SHUTTLE ACTIVE THERMAL CONTROL SYSTEM

DEVELOPMENT TESTING

VOLUME II

MODULAR RADIATOR SYSTEM TESTS

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FOREWORD

This volume is one of a series of reports describing the development tests conducted on a candidate Shuttle heat rejection system at the National Aeronautics and Space Administration - Johnson Space Center during the period from March to July 1973. The complete test series are reported in the following volumes:

Volume I	Overall Summary
Volume II	Modular Radiator System Tests
Volume III	Modular Radiator System Test Data Correlation With Thermal Model
Volume IV	Modular Radiator System Test Data
Volume V	Integrated Radiator/Expendable Cooling System Tests
Volume VI	Water Ejector Plume Tests
Volume VII	Improved Radiator Coating Adhesives Tests
Volume VIII	Tube Anomaly Investigation

The tests were conducted jointly by NASA and the Vought Systems Division of LTV Aerospace Corporation under Contract NAS9-10534. D. W. Morris of the NASA-JSC Crew Systems Division was the contract technical monitor. Mr. R. J. Tufte served as the VSD Project Engineer.

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1.0 SUMMARY

A three-week test of a Modular Radiator System (MRS) was conducted in the Space Environment Simulation Laboratory (SESL) at the Johnson Space Center (JSC) during the time period March 5 through 23, 1973. The tests were designed to investigate the validity of the "modular" approach to space radiator system design for Space Shuttle and future applications by gathering performance data on various systems comprised of different numbers of identical panels, subject to nominal and extreme heat loads and environments. Both one-sided and two-sided radiation was tested, and engineering data was gathered on simulated low α/ε coatings and system response to changes in outlet temperature control point.

The results of the testing showed system stability throughout nominal orbital transients, unrealistically skewed environments, freeze-thaw transients, and rapid changes in outlet temperature control point. Various alternative panel plumbing arrangements were tested with no significant changes in performance being observed.

With the MRS panels arranged to represent the Shuttle baseline system, a maximum heat rejection of 76,600 BTU/hr was obtained in segmented tests under the expected worst case design environments. The minimum heat rejection was 8260 BTU/hr in a cold environment. Testing of an alternate smaller two-sided radiation configuration yielded a maximum heat rejection of 52,931 BTU/hr under the maximum design environments and a minimum of 4163 BTU/hr in a cold environment.

2.0 INTRODUCTION

This report presents data from the Modular Radiator System Shuttle Configuration Tests conducted in the NASA-Johnson Space Center thermal vacuum facility (Chamber A) from 5 March 1973, through 23 March 1973. The tests were conducted under the supervision of the Crew Systems Division of JSC. Vought Systems Division of LTV Aerospace Corporation designed, manufactured, and instrumented the radiator panels and flow bench used to supply the radiator system. The chamber facilities, environment simulation and data gathering and reduction were supplied by NASA-JSC.

2.1 Test Objectives

The general test objectives were:

1. Provide data which will support detail design of Space Shuttle radiators by defining performance limitations with environments and fluid temperatures characteristic of shuttle operation.

2. Demonstrate performance of eight modular radiator panels in a variety of series and parallel flow arrangements with balanced and unbalanced panel environments.

3. Demonstrate that the modular radiator system performance range of capabilities satisfies Shuttle requirements.

4. Demonstrate general modular radiator system operational capability in a thermal-vacuum environment.

5. Investigate test performance of various candidate shuttle radiator panel arrangements to support analytical predictions.

6. Provide data for verification/correlation of math model predictions.

The test was divided into three major groups with specific objectives as follows:

GROUP 1 - SIMULATED SHUTTLE BASELINE SYSTEM - One-Sided Radiators

- o Demonstrate performance of the Rockwell International Corporation (RIC) baseline Shuttle configuration with a variety of heat loads and thermal environments.

GROUP 2 - TWO-SIDED RADIATORS

- o Demonstrate performance of radiator portion of weight optimum radiator-water heat rejection system under

simulated 78° inclination and 0° inclination orbits.

- o Investigate radiator system response to step changes in outlet temperature control point.

GROUP 3 - DESIGN DATA

- o Compare performance of radiator systems plumbed in various alternative arrangements.
- o Evaluate engineering design adequacy of the panels.
- o Evaluate performance with simulated low α/ε coatings.
- o Demonstrate system parallel flow stability with skewed environments.
- o Demonstrate system performance during transition between high and low heat loads (freezing and thawing) in various parallel/series flow arrangements with balanced and unbalanced environments.

Four basic Shuttle configurations were approximated during the test. The four configurations have been analyzed in a recent Shuttle radiator design optimization study (Reference 1) which permitted the use of water evaporation to supplement radiator heat rejection when needed. The four configurations and corresponding flow loops are illustrated in Figure 1.

The baseline configuration (3) with 1436 ft^2 of effective area can reject the Shuttle heat loads without supplemental water evaporation. For each cargo bay door, two panels are permanently attached to the aft door segments and four more panels are mounted back-to-back and separately deployed from the forward door segment. The 12 panels are identified as A through L on Figure 1.

Configurations 1 and 2 require supplemental water evaporation to satisfy shuttle heat rejection requirements, but all panels are permanently attached to (and supported by) cargo bay door segments. Configurations 1 and 2 differ only in the deployment angle of the forward doors. The eight panels are identified ABCD, GHIF and tne environments are similar to those of Panels ABCD, GHIF of Configuration 3 .

Configuration 4 consists of four panels which are separately deployed from the forward cargo bay door segments. The panels are uninsulated so that they radiate from both sides. The analytical trade study indicated that, with supplemental water evaporation, this concept yielded a weight optimum design. The four panels are identified as M, N, O and P since the two-sided configuration

does not correspond to any panels in the other three configurations.

2.2 Mission Environments Simulated

Figures 2 and 3 show the various mission environments which were simulated during the testing. In addition, deep space cold soaks and severely skewed (unrealistic) environments were simulated. Detailed values for the environments are presented in the section on evaluation of results and in Appendix A.

3.0 TEST ARTICLE AND INSTRUMENTATION

3.1 Panel Description

The Modular Radiator System (MRS) for this test consisted of eight 6 ft x 12 ft flat panels arranged in flow patterns similar to those being considered for the Space Shuttle. Each panel consists of extruded tubes welded to 0.02 inch aluminum sheet on 6.0 inch centers in a U-shaped pattern as shown in Figure 4. The over/under tube arrangement (Figure 4) provides for completely redundant flow passages, but only the "under" passage was used in this test. Thorough thermal vacuum testing of two of the panels has previously been performed (Reference 2) and all eight panels and the flow bench were checked out in the VSD thermal vacuum chamber prior to the Chamber A tests to insure satisfactory operation of all equipment and verify all operational procedures. (Reference 3)

The eight panels were installed in Chamber A as shown in Figures 5 and 6. Figures 7 through 9 show the panel being insulated, the plumbing insulation and the insulated panels. The environment simulators were installed directly below the radiator panels and wrapped in superinsulation as shown in Figure 10 for the one-sided and two-sided radiation tests.

3.2 System Description

The MRS achieves heat load control by varying the flow split between a "prime" and "bank" circuit as shown for a typical panel arrangement on Figure 11. The flow split was controlled during the test by a valve which sensed the mixed outlet of the prime and main circuits and compared it to a desired set point temperature. During periods of low load, the majority of the flow was routed to the prime tubes of each panel, and the bank was allowed to stagnate (freeze), thus reducing the effective panel area. As the load increased, more flow is routed to the bank, and the panels begin to destagnate (thaw) from the inside out (i.e., the shortest tubes destagnate first).

Two different mixing valves were used during the test to control the prime and main mixed temperature. A thermally actuated valve supplied by Pyrodyne was used during some portions of the test (mostly during transients). This valve has a fixed set point of 47-49°F.

The second valve used an electro-mechanical valve and control unit originally designed for use in the Skylab Apollo Telescope Mount (ATM) coolant

loop. The valve control unit was modified by LTV to provide outlet temperature control points of 40°, 50°, and 70°. The Skylab requirement for leakage through the ATM valve "closed" side is much higher than that required for MRS testing. Thus, additional restriction was added manually by LTV test personnel during various phases of the test, such that the leak rate was reduced to approximately 1% of full flow.

Figure 12 shows the test system schematic and instrumentation location. All valves inside the chamber are remotely controlled to permit a wide variety of series/parallel flow arrangements. Some valves external to the chamber used to provide for flowmeter isolation for servicing and repair and an additional temperature control valve (the ATM valve)are not shown on Figure 12 .

3.3 Instrumentation

The A1 series thermocouples (panel inlet and outlet temperatures) and flow measurements shown on Figure 12 are considered critical for evaluating system performance. The A1 temperatures are backed up by Brown Recorder thermocouples and the flowmeter arrangement (total flow plus flow in each leg) is such that with the loss of any one flowmeter all flows are still known. In addition to the critical fluid temperatures, each panel has 37 thermocouples attached to the external tubes as shown in Figure 13. These temperatures and the panel pressure drop measurements are desirable but not considered critical to the conduct of the test.

Figures 14 through 17 show the LTV flow bench and equipment used to supply the radiator system with the desired fluid temperatures and flow.

During the third week of testing it was observed that the inlets to the prime tubes inside the chamber were reading approximately 9°F higher than the prime inlet outside the chamber. With chamber cold walls it did not seem reasonable that a net heat gain of this magnitude could occur. Starting with day 79 approximately 2230 hours the back-up thermocouples for A10003 through A10036 were recorded on the miscellaneous channels, MS0003 through MS0036. The MS data agreed well with the measurements outside the chamber. Subsequent to the test it was discovered that a dissimilar thermocouple connector inside the chamber was used for A10003 through A10014. During the first two weeks of testing the chamber walls were warm and the thermocouple connector did not affect the readings. However, during the third week the

chamber walls were cold and a temperature gradient in the connector produced an EMF which affected the readings. A survey of the Al and MS readings after 2230 on day 79 indicated that the Al readings averaged 8.5°F high. This value was subtracted from all A10003 through A10014 data between day 78, 0735 hours and day 79, 1110 for determining the radiator performance.

3.4 Environment Simulation

The environment was simulated by a temperature controlled panel located immediately below the radiator panels as indicated in the sketch of Figure 10. A freon 11 loop and a liquid nitrogen loop flowing in separate tubes were used to control the panel temperatures. Design, installation and operation of the environment panels were provided by the Space Environment Simulation Laboratory (SESL) division of NASA-JSC. The radiator panel absorbed heat was determined by SESL engineers based on the simulator and radiator temperatures including the effect of reflected energy.

Appendix A shows the absorbed heat for each radiator panel at the stable conditions. Transient environment data is not available at this time. During the initial 5 test points the simulated environment was high because SESL engineers used a radiator panel emissivity of 0.85 to determine the heat absorbed. VSD used 0.92 in the pre-test computer analysis. Gier-Dunkle tests of 5 paint samples by NASA indicated a "near normal" emissivity of 0.913. Correcting to hemispherical emissivity yields 0.865 to 0.89. A value of 0.90 was used to determine all the environments shown in Appendix A. TP-5 (Test Point - 5) environments were set based on the revised emissivity of 0.90, resulting in lower values than used in TP-1. TP-1 and TP-5 are segments of the baseline system and together simulate one side of the cargo bay doors. This explains why the environments for this test sequence were inconsistent.

4.0 TEST DESCRIPTION

The original test plan called for three separate test weeks with different panel and plumbing configurations each week. In order to make maximum use of available test time the test chamber pumpdown was to be initiated at midnight each Sunday and the test completed in time for repressurization and required test article reconfiguration by midnight the next Friday. However, a failure of the environment simulator during the first week of testing required a revision of the test timelines including chamber repressurization and pumpdown in the middle of the week one and week three tests. The revised test plan satisfied all major test objectives although the test time was reduced.

4.1 Test Description by Week

During the first week the panels were insulated on one side and two flow loop arrangements tested to investigate the performance of segments of configurations 1, 2, and 3. Flow loop α (Figure 18) is used to simulate the top panels on one cargo bay door for configurations 1 and 2; all of the panels of configuration 2 with a low α/ε coating; and 1/4 of the upward facing panels combined with all of the downward facing panels of configuration 3.

Flow loop β (Figure 19) simulates the parallel to series flow setup of the baseline system for one cargo bay door. One half of the upward panel area and all of the downward facing area are simulated for this test arrangement. Since the flow loop of Figure 18 simulates all upward facing panels of configuration 3, the outlet temperature at point X (after one half of the upward facing panels) is used at the inlet temperature for corresponding conditions with flow loop β (Figure 19). The temperature at point Y (after 3/4 of the upward facing panels) is used as the inlet temperature for corresponding conditions with the arrangement of Figure 20 which simulates the outlet leg of both cargo bay doors. Figures 21 and 22 summarize the first week test configurations and flow of testing.

After 5 test points were completed in the first week,a freon 11 line supplying the IR simulator failed causing a pressure wave in the chamber to blow the insulation blankets off of panels 3 and 4 and partially off of panels 2 and 7. Figure 23 shows the insulation on the panels after the freon 11 line failure. It was decided that no further useful testing could be accomplished with the panels exposed to the chamber warm walls so the chamber was repressurized and

the blankets and line repaired. The test timelines were revised to reflect the reduced test time due to the chamber repress, repair time and pumpdown. During the first test sequence after pumpdown, another IR panel line failed (Zone 2) and blew the insulation blanket partially off of panel 2. The flow arrangement was modified to use panel 6 and 8 instead of 2 and 4 in the α flow loop and one orbit simulation completed before another IR panel line failed and blew the insulation off of panel 8 and partially off of 6 and 7. Figure 24 shows the location of the insulation blankets after the second and third IR panel line failures. Four additional planned test points were completed with revised flow configurations and degraded insulation on panels 2, 6, and 7. Two additional test points were devised to investigate system performance during the transition from low to high heat loads and with the panels under widely different environments.

The second week of testing was revised to complete the originally planned week 1 test points and a portion of the planned third week tests. The third week of testing was planned to investigate three more flow loops (Figures 25, 26 and 27) to demonstrate versatility of flow arrangements, the effect of panel isolation, panel shadowing, and limitations on performance. Freeze-thaw characteristics of panels connected in various parallel/series flow arrangements were also obtained during these tests. Figure 28 summarizes the second week configurations.

Based on anomaly study results of the IR panel failures, the requested environments for the remaining tests were also revised so that the cyclic environments did not require alternate freon 11 and LN_2 in the simulator panels. All major third week objectives were accomplished during the second portion of the second week.

For the third week of testing, the insulation was configured to simulate the cargo bay door and the performance of configuration 4, (two-sided radiation) investigated with flow loop γ (Figure 29). This flow loop simulates the radiators on both sides of the forward 30 ft. of the cargo bay and represents the full radiator system when expendable water is used to supplement the radiator heat rejection. All planned test sequences and objectives were accomplished for this configuration. Excess test time at the end of the week was utilized to investigate the system performance in other than the analytical "worst case" orbits.

Table 1 presents the complete 3 week test timelines in the order the tests were run. Appendix B presents more detailed test timelines compiled from the weekly status reports prepared by VSD.

4.2 Summary of Testing by Objective

The sixty-one test points run during the three-week test series have been divided into three major groups as follows:

Group 1 — Simulated Baseline System

- Sun in Cargo Bay, β = 78° environment
- Skewed environments
- Cold soak and recovery

Group 2 — Two-Sided Radiator System

- Sun in Cargo Bay, β = 78° environment
- β = 0° environment
- Cold soak and recovery

Group 3 — Design Data

- Low α/ε coating simulation
- Response to set point changes
- Alternative plumbing arrangements

5.0 TEST RESULTS

The results presented in this section are catagorized by major objective topic as presented in Section 4.2. Section 5.1 presents simulated baseline results, Section 5.2 presents two-sided radiator results, and Section 5.3 contains results from other test points designed to obtain engineering data.

Each major group has been further subdivided to include test points which together form the baseline system or are directly comparable to each other. Tables 2 through 4 present the test point groupings and an index showing the page numbers for the test data for each subgroup. The test results presented include a summary of the test conditions and overall results, steady-state performance maps showing temperatures and flow rates for each stabilized condition and appropriate transient data and calculated heat rejection as required. The complete set of test data is presented in Volume IV of this report.

5.1 Baseline System

The results of Test Groups 1.1 through 1.8 (refer to Table 2) are displayed in this section. Table 5 summarizes the results of these groups (18 test points) and Tables 6 through 12 present a summary chart for each group. Figures 30 through 55 present detail data for each test point.

Table 5 shows the test data heat rejection for the simulated baseline system. For those test points which simulate half of the system the average heat rejection over the orbit is doubled to get the system heat rejection. It is assumed that as one side of the system is at the maximum heat rejection the other side is at the minimum so that the orbital average of one side is approximately the same as the total system. Table 5 indicates that test groups 1.1 through 1.5 do not reject the desired heat loads. The difference in heat rejected and heat load for test groups 1.6 and 1.7 is due to the outlet temperature control point and slight differences between the main and prime system flow splits between the test segments. The fact that test groups 1.1 through 1.5 do not reject the heat load is attributed to two reasons. First, although the total test area agrees with the baseline area, the distribution between the top panels and the cavity panels is different. Second, the test environments are generally higher than desired resulting in a lower heat rejection.

The test and baseline areas are:

	TEST	BASELINE
Top Panels	1152	1030
Cavity Panels	288	410
Total	1440 Ft^2	1440 Ft^2

The baseline heat rejection can be estimated by adjusting the test heat rejection on the top panels and cavities by the differences in areas. Table 18 presents the results of this analysis for test groups 1.1, 1.2 and 1.5. The extrapolated results are close to the desired heat rejection for test groups 1.1 and 1.2 indicating that with lower environments the heat load could be met. The results for test group 1.5 indicate that the baseline system as tested will not reject the system heat load with the sun in cavity orientation. A flow reversal valve which routes the flow through the hot cavity panels first then to the top panels or a flow proportioning valve to route the flow to the cold cavity would improve heat rejection for this orientation.

The low heat rejection for test groups 1.3 and 1.4 is attributed to higher than desired environments. For example, the comparison of test points 5 and 8 shown in Figure 55 indicates that the high environment on panels 1, 3, 5 and 7, test point 8, caused the inlet to the cavity panels (panels 8 and 6) to be the same for both test points and resulted in the same outlet temperatures.

5.2 Two-Sided Radiation Tests

The environment and heat load simulation for this test group was very good. No data is available at this time on the transient environments but the maximum and minimum points agreed well with the desired values.

Test groups 2.1 through 2.4 examined the performance of the radiator portion of the analytically determined weight optimum radiator/water heat rejection system. Table 13 summarizes the test results of these test groups and Figures 56 through 86 present the temperature maps and pertinent transient temperature and flow rate plots. Test points 21 and 22 yield comparable results for steady state and cyclical environments. As indicated by Table 13, the test heat rejection rate for TP-21 would require an additional 20,296 BTU/hr of heat rejection by water evaporation to reject the imposed heat load of

69,722 BTU/hr. This is above the nomial 16 lb/hr maximum previously established by analysis for the evaporation device. An examination of the environments for this test point indicates that the steady environments requested were too high. The cyclic environments used for TP-22 varied between 133 and 158 for one side of the cargo bay and 171 and 131 (90° out of phase) for the other side. Therefore the constant environment of 160 BTU/hr-ft^2 on all panels used in TP-21 is not representative of the design conditions. This data point is valuable as a steady maximum heat rejection case for thermal model correlation. TP-22 indicates a maximum evaporation heat load of 17,864 BTU/hr which is close to the nominal 16 lb/hr rate. It should also be noted that the maximum heat rejection occurred during TP-27 which represents a sun in cavity orientation. This is in direct contrast to the baseline system which indicated that the sun in cavity orbit is the worst case condition.

Calculated heat rejection rates (Table 13) for the initial seven test points were approximately 10 percent lower than the pre-test predictions (a maximum deviation of 3000 BTU/hr). Heat rejection rates for the low load tests were different from the simulated loads and predictions due to slight differences in the outlet control point. The differences in the predicted and test heat rejection for the high and intermediate loads could be caused by several factors. The total heat absorbed by the radiators was higher than used in the predictions due to the effect of the warm chamber floor and the radiant interchange between the insulation blankets which face each other (panels 2, 4, 5, and 7). The pretest analysis to determine the angle between the blankets and the panels indicated that an angle of 42° is desired for the outward facing blankets and 48° for the blankets that face each other. The actual test configuration had all blankets at approximately 45°. It is estimated that the effect of the warm chamber floor and the LN_2 walls adds 3.3 to 7.2 BTU/hr-ft^2 for a chamber floor temperature of 0°F and -100°F respectively (LN_2 walls at -280°F). Real time computer analyses were conducted during the test with 3-4 BTU/hr-ft^2 added to the observed test environments from the IR simulator panels. The effect on outlet temperature for test points 21 and 22 are:

	TP-21	TP-22
Pretest Analysis		
Outlet temp, °F	74	67.1-70.9
Q_{ABS}, BTU/hr-ft^2	160	133-158 171-130
Real Time Analysis		
Outlet Temp	76.2	68.8-72.0
Q_{ABS}	164.8	135-165 174-132
Test Results		
Outlet Temp	78	71-74
Q_{ABS}	?	?

It is seen that radiator performance is very sensitive to environments in this range. A change in absorbed heat from 158 to 165 BTU/hr-ft^2 increases the equivalent radiation sink temperature approximately 6°F from 51 to 57°F.

Another possible reason for the lower than anticipated panel heat rejection is that the effective radiation from the simulated cavity could be lower than the pre-test analysis value. Previous cavity analyses of the actual shuttle configuration including the effect of the curved surfaces indicated that the effective area of the cavity panel was 67% of the actual panel area. It was originally planned to conduct the test with 33% of the panel covered with an insulation blanket to simulate the cavity. However, a late NASA requirement that the test configuration be more geometrically representative of the Shuttle required the analysis to determine the angle between the flat test panels and insulation blankets that would yield an effective area of 67% of the panel area. Due to time limitations this analysis was based on the simplifying assumption that considered the radiator panel as one isothermal node and the blanket as one isothermal node. More detailed multi-node analyses may indicate a lower effective radiation from the test cavity.

Test group 2.4 examined the weight optimum radiator system performance in a simulated 0° inclination orbit. These orbits have been analytically shown to be not as severe as the 78° inclination orbits tested in test group 2.1. A comparison of the results verifies that less water evaporation is required for test point 22. However, the peak outlet temperature occurs during TP-61 indicating that the maximum instantaneous water evaporation rate is during this orbit. This is important in sizing the evaporation system. The test data

indicates a maximum water evaporation device heat load of 19,048 BTU/hr. An examination of the transient test environments to insure that they are representative of the orbit and an analytical verification of the results is required before a definite design criteria is established. The maximum and minimum test environments were lower than requested (a maximum deviation of 5.0 BTU/hr) indicating that the actual peak outlet temperature could be higher than the test data.

Groups 2.5 through 2.8 are included in the two-sided radiation test subgroup, although these tests were primarily intended to test system outlet temperature set point change response. Table 14 summarizes the test results of test groups 2.5 through 2.8. Figures 78 through 81 show the transient heat rejection resulting from the change in set point temperature and flow rate and outlet temperature plots. As shown by Figures 78 through 81 the changes in radiator heat rejection are accomplished in five minutes or less, indicating that the water evaporation device to be used with the radiator system should have a fast response time. As previously mentioned, the flow control valve used to control the mixed outlet temperature required some manual override to maintain the desired outlet. This accounts for the loss in outlet control observed in some cases immediately after a change in set point. The test data indicates that the radiator system's ability to supply a controlled outlet temperature of 40°F to 70°F is limited only by the response time of the control valve. With the control point set at 70°F the main outlet temperature is less than 40°F, due to reduced flow, even at high load and hot environment. (The load/environment must be such that the radiator system is capable of obtaining a 40°F outlet of course.) When the set point is changed to 40°F the control valve routes more flow through the main system and the first slug of cold main fluid immediately lowers the mixed outlet to 40°F. With the control point maintained at 40°F, the prime outlet remains approximately 3°F below the inlet temperature even at low loads in the coldest environment. When the set point is increased to say 70°F, the first slug of hot prime fluid immediately increases the mixed outlet.

The maximum observed change in heat load was from approximately 45,000 to 70,000 BTU/hr (Test Points 53-54 and 56-59). This 25,000 BTU/hr change under the maximum load conditions is above the anticipated change in

load when the excess fuel cell water is used to top off the radiator system (10,000-16,000 BTU/hr). Test points 52D and 52E obtained the maximum observed heat rejection ratio of 7.7 : 1.0 (2600 to 20,000 BTU/hr). Test point 52 had a lower than desired heat rejection because the simulated heat load was low due to limited test equipment heater power for the prime system.

There were no observed flow instabilities (Figures 82 through 85) due to the rapid changes in flow rates for the cold and skewed environments. Figure 86 shows a typical flow rate response, indicating equal flow distribution in the four parallel flow paths.

5.3 Design Data

The test points grouped under design data include those intended to investigate (1) alternative plumbing configurations (Test Groups 3.1 through 3.3), (2) response to heat load transients and recoveries of frozen panels (Test Groups 3.4 and 3.5), and (3) low α/ε coating simulation (Test Groups 3.6 and 3.7).

Alternative Plumbing Arrangements

Table 15 summarizes the alternative plumbing test points and Figures 87 through 98 present the temperature maps for these test points.

A comparison of the heat rejection per unit area (Q/A) is shown in Figure 99 for panels plumbed in 4, 5 and 8 parallel paths. This data indicates that with equal panel inlet/outlet temperatures (TP-32, 33 and 45), the Q/A variation is 51.0 to 55.4 BTU/hr-ft^2. TP-46 has a Q/A of 62.5 BTU/hr-ft^2, but also has a higher outlet temperature indicating a higher average radiating temperature. Therefore, a direct comparison between TP-46 and TP-32, 33 and 45 cannot be made. It is concluded that changing the panel plumbing from 4 to 8 parallel paths results in approximately an 8 percent decrease in heat rejection capability. This agrees with previous analytical studies (pre-test predictions which were made for an inlet temperature of 111°F instead of 165°F).

The effect of different plumbing configurations for the cavity panels of the baseline system is shown in Figure 100. TP-48 and 49 indicate no difference in system performance. The difference between TP-20 and TP-48 and 49 is attributed to differences in environments. The test results again indicate that the plumbing arrangement does not affect the system performance.

Test points 37, 38 and 39 were intended to provide a comparison of plumbing arrangements under low load operation. However, an evaluation of the results (Figures 91, 92 and 93 indicates that the test conditions chosen for these test points were incorrect. The environment of 11^ BTU/hr-ft^2 on all panels except 7 and 8 with an inlet temperature of 53°F resulted in heat rejection only in panels 7 and 8. The other panels actually absorbed heat. Under the test conditions no difference in panel 7 and 8 performance was observed and the isolation of panel 8 merely reduced the system heat rejection by approximately one-half.

The only other comparison of low load plumbing arrangements is provided by test points 16 and 43. As shown on Figure 101, test point 16 heat rejection was lower than test point 43. This is attributed to differences in the mixed outlet control point rather than better low load capabilities of the test point 16 plumbing configuration. A comparison of the main outlet temperatures, indicates that during test point 43 the panels got colder than during test point 16, although neither test point approached the limit of -211°F. This is due to different environments (the test points were not originally designed for comparison).

The test data are inconclusive as to the best plumbing arrangement to obtain the lowest load. It is expected that a flow arrangement with all panels in series would have a lower load capability than all panels in parallel since the downstream panels would have a lower inlet temperature and lower average temperature in the series arrangement. No test data was obtained under limit conditions to verify this hypothesis.

Heat Load Transients

A total of 6 heat load transients with five different flow configurations were conducted (Test Groups 3.4 and 3.5). A summary of the heat load transient test points is shown on Table 16. Panel temperatures prior to the recovery and panel flow rates and outlet temperatures during the recovery are presented in Figures 102 through 128. Minimum-maximum-minimum and maximum-minimum-maximum heat load transients were tested with different environments on parallel panels. A maximum of five parallel panels with a hot environment on one panel and cold environments on the other four have been tested. All flow arrangements operated satisfactorily, with no observed flow instabilities. Figures 102 through 107 show the coldest tube temperature taken

from the 37 panel thermocouples (Figure 13) at the minimum heat load condition just prior to the start of the transient to the high heat load condition. This data indicates the number of tubes which must be thawed during the transient.

Figures 107 and 114 show the flow rates in parallel flow paths during the heat load transients for test points 47 and 19 respectively. As indicated, there were no flow instabilities observed during either transient. The flow discontinuity shown on Figure 109 at 1600 hours is due to a flowmeter failure.

Figures 120 through 124 show the recovery transient of each tube of panels 2, 3, 5 and 6 during test point 50. A comparison of tube 3 temperatures during the test point 50 recovery, given on Figure 124, shows the transient characteristics of five panels plumbed in parallel. At the start of this transient four of the five parallel panels had six tubes frozen (Figure 104). Panel 1 had a high environment (approximately 125 BTU/hr-ft^2) and did not freeze any tubes, thus demonstrating flow stability with partially frozen and free flowing panels in parallel. Further evidence of this stability is indicated by the fact that all panels show a recovery trend throughout the transient even though the panels do not thaw out at the same time due to differences in initial temperatures (Panel 5 was the coldest panel), environments and/or panel inlet temperature and flow rates. The last panel to recover (Panel 5) lags the initial panel recovery by approximately 20 minutes. The exception to the consistent recovery trend is shown by a comparison of tube temperatures of panels 2 and 3 (Figures 120 and 121). Panels 2 and 3 appear to be recovering at approximately the same rates when Panel 3 abruptly experiences a trend reversal for a short period of time. This is believed to be caused by Panel 2 tubes thawing first and momentarily taking the majority of the flow (in effect starving Panel 3) due to the reduced pressure drop caused by more tubes flowing. The recovery trend is quickly re-established however, indicating the system stability.

Test group 3.5 was designed to investigate the heat load transient under cold environments. As indicated on Figure 105, only panel four was frozen during test point 17A-18. Panel two had one tube that was frozen, but due to the degraded panel insulation, the heat leak to the warm chamber walls kept the other tubes above the freezing point. Figure 126 illustrates the flow stability of panels in two parallel flow paths during the heat load transient. The flow blips between 0 and 0100 hours are caused by surges in the total flow.

Figures 127 and 128 demonstrate the flow stability of panels in three and four parallel flow paths respectively. As shown by Figures 105 and 106 both the upstream and downstream panels had frozen tubes and there were different number of frozen tubes at the start of the transient. For example, both panels 6 and 8 had eight frozen tubes at the start of test point 60-51, whereas the parallel panels 2 and 4 had only one and five tubes frozen.

Simulated Low α/ε Coatings

The low α/ε coating performance was simulated by reducing the absorbed heats to the analytically determined values and ratioing the test panel areas by the ratio of emissivities ($\varepsilon_{white\ paint} / \varepsilon_{desired} = .9/.76$). Table 17 summarizes the results of this group of tests and the test panel and simulated areas. Test points 31, 36 and 36A represented one-half of the analysis configuration 2 under steady environments and test point 2 represented the full configuration 2 with cyclical environments. Figures 129 through 133 present temperature maps for test groups 3.5 and 3.6. Figures 134 and 135 show the flow rate and outlet temperature variations for the simulated orbit of test point 2.

Figure 136 compares the results of the simulated low α/ε coating tests to the analysis results of reference 1. Test point 2 compares very favorably with the analysis while test point 31 indicates a higher required evaporation than predicted. This is attributed to the fact that the test was conducted with steady rather than cyclical environments.

6.0 CONCLUSIONS

The modular radiator system operated flawlessly during three weeks of testing, accumulating over 300 hours of operation in a thermal-vacuum environment with no problems. Performance data has been obtained for Rockwell's baseline system and the weight optimum system for a variety of known environments and heat loads representative of the shuttle design conditions. Design data for alternate plumbing arrangements, heat load transient capabilities and simulated low α/ε coating operation have also been obtained. All test objectives have been met.

The maximum observed baseline system heat rejection was 76,600 BTU/hr obtained in segmented tests, and 52,931 BTU/hr for the weight optimum system. The minimum observed heat rejection was 8260 BTU/hr for the baseline system and 4163 BTU/hr for the weight optimum system. The test results indicate the applicability of the MRS to the Shuttle; however several differences between the test and baseline panels should be examined in future testing. These differences include: the panel size, the panel aspect ratio (length to width), and the reach (maximum distance between frozen and non-frozen tubes during low load). It is also recommended that future testing include the effect of backside and edge heat leaks.

The concept of modular radiator panels used to "build" a system to the required area was demonstrated by obtaining operating data for panels plumbed in eight different series/parallel arrangements with skewed and balanced environments representing eight different situations. Each of the test panels provided the same performance under similar heat loads and environments.

A total of 17 test points were made to collect design data to support detail design of the shuttle radiators. The test data indicates that any convenient plumbing arrangement can be used (up to eight panels in parallel) with only a slight degradation in performance due to low panel flows (laminar flow heat transfer coefficients). The transition between the minimum and maximum heat rejection rates was demonstrated for a variety of series/parallel flow configurations with balanced and unbalanced environments. No unstable flow conditions were observed during any of the tests.

The simulated low α/ε coating tests indicates that the MRS should operate satisfactorily with a low α/ε coating and that the performance is in

the range used in previous heat rejection system weight optimization studies.

Data for thermal model correlation has been obtained by recording total system and individual panel inlet and outlet and tube temperatures, flow rates and pressure drops for approximately 302 hours of testing. A preliminary comparison of pre-test predictions and test data indicates that the system model used in previous analytical studies is adequate. The results of a more detailed correlation analysis are reported in Volume III of this report.

7.0 REFERENCES

1. Howell, H. R., et.al., "Space Shuttle Heat Rejection System Optimization Study", LTV Memorandum No. 2-53002/73IM-8, 26 January 1973.
2. Dietz, J. B., et.al., "Modular Radiator System Development for Shuttle and Advanced Spacecraft", American Society of Mechanical Engineers Paper No. 72-ENAv-34, August 1972.
3. Howell, H. R., "Modular Radiator System Dallas Checkout Test Results", LTV Report No. T169-27, 9 October 1973.

TABLE I

THREE WEEK TEST TIMELINE

DATE	DAY	TEST POINT	BEGIN	END
5 March 1973	64	1	1525	1855
		1A	1855	2020
		2	2020	0146(day 65)
6 March 1973	65	3	0146	0445
		4	0445	0600
		Chamber Down	0948	1700
7 March 1973	56	5	1700	1920
8 March 1973	67	8	0020	0430
		10	0430	0755
		12	0755	1115
		17	1115	1525
		17A	2050	2256
		18	2300	0340(day 68)
9 March 1973	68	19	0740	1140
12 March 1973	71	47	1108	2025
13 March 1973	72	14	0000	0315
		14A	0315	0615
		16	0730	1040
		20	1040	1515
		11	1515	1830
		Chamber Down	1830	1400(day 73)
14 March 1973	73	31	1400	1525
		32	1525	1825
		33	1825	1920
		48	1920	2210
		49	2210	2330
		37	2330	0210(day 74)
15 March 1973	74	38	0210	0300
		39	0300	0400
		45	0400	0615
		46	0615	0745

TABLE I (CONT'D)

DATE	DAY	TEST POINT	BEGIN	END
15 March 1973	74	50	0745	1900
		43	1900	2335
		36	2335	0600(day 75)
16 March 1973	75	36A	0600	0955
19 March 1973	78	21	0736	1000
		22	1000	1340
		23	1340	1720
		24	1720	2025
		25	2025	2330
		26	2330	0130(day 79)
20 March 1973	79	27	0130	0250
		28	0250	0525
		29	0525	1110
		62	1110	0045
21 March 1973	80	57	0045	0420
		58	0420	0735
		60	0735	1140
		51	1646	1735
		52	1735	1920
		52A	1920	2031
		52B	2031	2105
		52C	2105	2200
		52D	2200	2336
		52E	2336	0205(day 81)
22 March 1973	81	53A	0205	0605
		53	0605	0715
		54	0715	0825
		55	0825	9:20
		56	0920	1105
		59	1105	1210
		63	1800	2144
		64	2300	0200(day 82)
23 March 1973	82	61	0200	0630

TABLE 2

TEST GROUP 1 - SIMULATED BASELINE SYSTEM TESTS

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT: CASE	DESIRED (BTU/hrft^2)	ACTUAL (BTU/hrft^2)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
1.1	Sun in C.B. one CBD sim. (1/2 of system) 80,000 BTU/hr	1A	α	Sun on Cargo Bay	130	137.49	178		32 80
		5A	β	Sun on C.B.	130	124.4	115	Same as test point 5	81
				Cyclical Cav.	0-60	14.8-79.5			
1.2	Sun in C.B. one CBD Sim. (1/2 of system) 70,000 BTU/hr	1	α	Sun on Cargo Bay	130	135.59	166		33 83
		5	β	Sun on C.B.	130	124.4	115	Insulation 30% off Panel 2	81
				Cyclical Cav.	0-60	14 8-79.5			
1.3	Sun in C.B. one CBD both cavities sim. 57,700 BTU/hr	3	α	Sun on Cargo Bay	130	139.23	142		35 84
		20	α	Sun on C.B.	130	124.3	100		85
				Alternating Cav.	20-60; 80-20	31.4-55.4; 78.5-35.35			
1.4	Sun in C.B. one CBD sim. 42,000 BTU/hr	4	α	Sun on Cargo Bay	130	135.8	116		37 87
		8	β	Sun on C.B.	130	140.1	96	Insulation 30% off Panel 2	88
				Cyclical Cav.	0-60	15.6-57.3			
1.5	Sun in Cavity Hot & Cold cavities separately & together with steady & cyclical Env. 70,000 BTU/hr	10	α	Top panels with sun in cavity	30	35.62	171	Half of α config. used	38 91
		11	β	Top	30	27.5	15.2		92
				Hot Cavity	180	181.4			
		12	β	Top	30	31.55	14	Degraded insulation on panels 2 and 7	93
				Cold Cavity	20	7.65			
		14	α_3	Top	30	30			94
				Cavities (Stdy)	20/180	30/180			
		14A	α_3	Top	30	28.36			95
				Alternating	180-20 20-180	171.9-31.6 28.8-153.3			

TABLE 2 CONT'D

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT CASE	DESIRED ($BTU/hrft^2$)	ACTUAL ($BTU/hrft^2$)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
1.6	Sun on belly one CBD and one CBD and both cavities sim. 7000 BTU/hr	17	α	Top Panel away from sun	20	24.6	55.3		41 99
		17A	β	Top	20	?	15		100
				Cavity to Space	0	4.2			
		16	α	Cavity	20-70	32.8-59.1	-91		101
				Alternat.	70-20	55.9-29			
1.7	Sun on belly one CBD sim. 70,000 BTU/hr	10	α	Top panels away from sun	20	35.62	171	Sun in cavity environment approx. equal to belly to sun for top panels.	43 91
		18	β	Belly to sun	20	28.4			104
				Cavity to space	0	7.8			

TABLE 3

GROUP 2 - TWO-SIDED RADIATION TESTS

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT CASE	DESIRED ($BTU/hrft^2$)	ACTUAL ($BTU/hrft^2$)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
2.1	Two-sided fwd 30' only-sun on cargo bay full system 78° simulation orbit	21	Y	Sun on cargo bay	160	160.79	163.2	Steady environments too high to represent design conditions	44 106
		22	Y	Left side Right side	136-161 174-133	132.4-161.6 170.3-128.3	162.7	70,000 BTU/hr load	107
		23	Y	Left side Right side	136-161 174-133	131.1-159.4 169-128.3	141.3	57,700 BTU/hr load	110
		24	Y	Left side Right side	136-161 174-133	125-155.2 166-125.5	115.5	42,000 BTU/hr	113
		25	Y	Left side Right side	136-161 174-133	127-152.3 165.3-124.8	95.3	31,000 BTU/hr	115
2.2	Two-sided, sun in cavity 78° orbit	26	Y	Hot side Cold side	174 70	168.8 67.3	117.3	42,000 BTU/hr	44 117
		27	Y	Hot side Cold side	174 70	171.5 67.2	164.9	70,000 BTU/hr	115
		28	Y	Hot side Cold side	174 70	167 68.5	52.4	7,000 BTU/hr	119
2.3	Two-sided, belly to sun 78° orbit	29	Y	Left side Right side	22-40 40-22	21.5-39.4 36.9-25.4	52.4	7,000 BTU/hr	44 120
2.4	Subsolar orbit	61	Y	Variable - see results section			167	Sun oriented - belly to sun	44 122
		63	Y	Variable - see results section			167	Earth oriented - cargo bay to earth	124
		64	Y	Variable - see results section			167	Sun oriented - cavity to sun	126

TABLE 3 CONT'D

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT CASE	DESIRED ($BTU/hrft^2$)	ACTUAL ($BTU/hrft^2$)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
2.5	Response to set point changes at low loads	57	Y	Deep space	0	3.84	53	Set point 40	45 128,132
		58	Y	Deep space	0	2.9	53	Set point 50	
		60	Y	Deep space	0	3.73	53	Set point 40	
2.6	Response to set point changes at high loads, low env.	51	Y	Deep space	0			Set point 40	45, 129,133
		52	Y	Deep space	0	7.7		Set point 50°F limited flow bench htr power prevented maintaining desired heat load	
2.7	Response to set point changes at intermediate load	52A	Y	Deep space	0	5	75	Set point 50°	45, 130,134
		52B	Y	Deep space	0	5.2	75	Set point 40°	
		52C	Y	Deep space	0	4.9	75	Set point 50°	
		52D	Y	Deep space	0	3.3	75	Set point 70°	136
		52E	Y	Deep space	0	5.2	75	Set point 40°	
2.8	Response to set point changes at high load, skewed environment	53A	Y	Hot cavity Cold cavity	130 0	120 11	163.3	Set point 40°	45, 131,135
		53	Y	Hot cavity Cold cavity	130 0	121.8 10.7	163.3	Set point 70°	
		54	Y	Hot cavity Cold cavity	130 0	126.6 14.1	163.0	Set point 40°	
		55	Y	Hot cavity Cold cavity	130 0	126.4 14.2	164.0	Set point 50°	
		56	Y	Hot cavity Cold cavity	130 0	122.7 10.48	163.0	Set point 70°	
		59	Y	Hot cavity Cold cavity	130 0	126.8 14.6	163.2	Set point 40°	

TABLE 4

GROUP 3 - DESIGN DATA TESTS

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT CASE	DESIRED ($BTU/hrft^2$)	ACTUAL ($BTU/hrft^2$)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
3.1	Compare inlet section of RIC baseline (top panels only) with various alternative plumbing arrangements. High load	32	γ	Sun on Cargo Bay	130	129.85	165.2	RIC Baseline	46,149 137
		33	δ	Sun on Cargo Bay	130	129.65	164.1	Aft 30' in parallel Fwd 30' in parallel	138
		45	ε	Sun on Cargo Bay	130	128.79	162.7	All in parallel	139
		46	ε -4,7,8	Cargo Bay to sun	130	129.8	162.7	Compare with TP45 for effect of high flow rate	140
3.2	Same as 4.1 Low load	37	γ	Sun 45° to Cargo Bay 7,8 shadowed	110/25	110/25	53	RIC baseline	46 141
		38	ε	Sun 45° to Cargo Bay 7,8 shadowed	110/25	110.4/25.1	53	Aft 30' in parallel Fwd 30' in parallel	142
		39	δ (-8)	Sun 45° to Cargo Bay 7 shadowed	110/25	110/7/26.6	53.0	One panel isolated; demonstrate flow stability	143
		62	γ	Panels shadowed	0	2.7	45	Super low load	144
3.3	Compare outlet section of RIC baseline (fwd 30' and cavity) with alternative plumbing.	48	δ	Sun on Cargo Bay Cavity	130 20/80	129.05 29.7/81.2	100	Compare with TP 20	46, 150 146
		49	γ	Sun on Cargo Bay Cavity	130 20/80	128.5 29.6/76.6	100	Compare with TP 20; Each cavity panel in series with a top panel.	147
		43	γ	Cargo Bay cold Cavity	20 20/80	8.35 10.1/51.4	-14.1	Compare with TP 16; Each cavity panel in series with a top panel.	148
3.4	Max-Min transient with skewed environment	47	α	Sun on C.B. 1/2 of panels shaded	130/0	125.4/7.3	53 162 53		47,169 152,158
		19	α	No realistic case	See Text	See Text	162 53 162	Panel 8 insulation completely gone.	153,163
		50	ε -4,7,8	One panel hot	130 0	130.4 9.5	45.6 to 160.4		154,170

TABLE 4 CONT'D

TEST GROUP	DESCRIPTION	TEST PT.	CON-FIG.	AVERAGE ENVIRONMENT CASE	DESIRED ($BTU/hrft^2$)	ACTUAL ($BTU/hrft^2$)	INLET TEMP. (°F)	REMARKS	DATA ON PAGE
3.5	Max-Min transients with cold environments	17A-18	β	Belly to Sun	20	28.4			47 155,176
				Cavity to space	0	7.8			
		36-36A	γ -1,3	Panels shaded	0	13.47	56.3 to 159.8		156,177
		60-51	γ	Panels shaded	0	3.73-12.71	53 to 159	Exceeded heat load simulation capability of prime system flow bench unable to maintain inlet temp/flow at desired levels throughout transient.	157,178
3.6	Analysis config. 2 (fwd 30' lowered in front of wing) 1/2 of System simulated, low α/ε coating	31	γ -1,3	Hot Side	60/52	58.6/52.2	162.1	Max Load - Hot Env.	48 179,186
		36	γ -1,3	Cold Side	0	3.87	56.3	Min Load - Cold Env.	180
		36A	γ -1,3	Cold Side	0	13.47	159.8	Max Load - Cold Env.	181
3.7	Analysis config. 2 weight optimum low α/ε coating, full system simulated	2	α_2	Sun on Cargo Bay	Variable See Text	See Text		Max Load - Hot Env.	48 182,186

TABLE 5

SIMULATED BASELINE SYSTEM TEST SUMMARY

TEST GROUP	HEAT LOAD 1000 BTU/HR DESIRED	ACTUAL	SIMULATED ORBIT SUN ON	ENVIRONMENT, BTU/HR CAVITY	TOP	SYSTEM HEAT REJECTED 1000 BTU/HR
1.1	80	79.4	CB	0-60 (14.8-59)	130 (135.6)	72.5-68.4
1.2	70	70.5	CB	0-60 (14.8-59)	130 (137.5)	65.7-61.6
1 3	57.7	57.4	CB	3-42 ; 61-0 (31-51);(60-35)	130 (139.2)	50.5 - 48.2
1.4	42	41.6	CB	0-60 (15.6-57.3)	130 (135.8)	39.7 - 29.5
1.5	70	66.8	CAVITY	216-20 ; 20-216 (172-32);(29-153)	30 (35.6)	64.5 - 61.3
1.6	7	9.6	BELLY	70-20 ; 20-70 (56-29) ; (33-59)	20 (24.6)	8.3
1.7	70	72.[illegible]	BELLY	0-20 (7-28)	20 (35.6)	69.1

TABLE 6

TEST GROUP 1.1 SUMMARY

TEST CONDITIONS		
● TEST POINT 1A	DESIRED	ACTUAL
Average Environment, BTU/hr-ft^2	130	135.6
Inlet Temperature, °F	177.8	178.3
Total Flowrate, lb/hr	1100	1107.2
Simulated Heat Load, BTU/hr-ft^2	80,000	80, 618
● TEST POINT 5A		
Average Environment on Top Cargo Bay Door Panels(1,3,5&7) BTU/hr-ft^2	130	124.4
Average Transient Environment On Cavity Panels, BTU/hr-ft^2		
Panel 6	0-60	13.8-58.7
Panel 8	0-60	15.8-59.3
Inlet Temp (From TP-1A) °F	118	114
Total Flow (From TP-1A) °F-lb/hr	1107.2	1107.6
Simulated Heat Load (From TP-1A) BTU/hr	21,600	20,385

TEST RESULTS	PREDICTED	ACTUAL
● TEST POINT 1A		
Temperature at Location "X", °F	117.4	118
Heat Rejection to Location "X", BTU/hr		36,920
● TEST POINT 5A		
Main Outlet Temperature, °F	39.3-60.1	43.7-61.6
Heat Rejected, BTU/hr		35,620-31,508
● TOTAL HEAT REJECTED, BTU/hr	80,000-68,400	72,540-68,428

REMARKS

- Requirements for TP-5 and TP-5A were so similar that TP-5 was actually used for TP-5A
- Heat load simulation was good
- Higher than desired absorbed fluxes caused higher than predicted system outlet temperatures
- Only one orbit was simulated before environment simulator failed. (Start-up transients may affect first orbit)

TABLE 7

TEST GROUP 1.2 SUMMARY

TEST CONDITIONS	DESIRED	ACTUAL
o TEST POINT 1:		
Average Environment, BTU/hr-ft^2	130	137.5
Inlet Temperature, °F	162.4	163.6
Total Flowrate, lb/hr	1100	1074.5
Simulated Heat Load, BTU/hr	70,000	69,940
o TEST POINT 5:		
Average Environment on Top Cargo Bay Door Panels (1,3,5,&7) BTU/hr-ft^2	130	124.4
Average Transient Environment on Cavity Panels, BTU/hr-ft^2		
Panel 6	0-60	13.8-58.7
Panel 8	0-60	15.8-100.2
Inlet Temperature (From TP-1), °F	114	114
Total Flow (From TP-1), lb/hr	1074.5	1107.6
Simulated Heat Load (From TP-1), BTU/hr	19,860	20,385

TEST RESULTS	PREDICTED	ACTUAL
o TEST POINT 1:		
Temperature @ Location "X", °F	111.1	114
Heat Rejection to Location "X", BTU/hr		30,050
o TEST POINT 5:		
Main Outlet Temperature, °F	32.8-58.8	43.7-61.6
Heat Rejection, BTU/hr		35,620-31,508
o TOTAL HEAT REJECTION, BTU/hr (Test Points 1 and 5)	70,000-59,300	65,670-61,558

TABLE 7 (Cont'd)

TEST GROUP 1.2

REMARKS

- Heat load simulation was good.
- Higher than desired absorbed fluxes caused higher than predicted system outlet temperatures.
- Only one orbit was simulated before environment simulator failed (start-up transients may affect first orbit)

TABLE 8

TEST GROUP 1.3 SUMMARY

TEST CONDITIONS

	DESIRED	ACTUAL
• TEST POINT 3:		
Average Environment, BTU/hr-ft^2	130	139.2
Inlet Temperature, ^oF	142.1	142.1
Total Flow Rate, lb/hr	110.0	1120.3
Simulated Heat Load, BTU/hr	57,700	58,000
• TEST POINT 20:		
Average Environment on Top Cargo Bay Door Panels (1, 3, 5 & 7) BTU/hr-ft^2	130	124.7
Average Transient Environment on Cavity Panels BTU/hr-ft^2		
Panels 2 & 4	3-42	30.6-56.5
Panels 6 & 8	61-0	79.7-35.0
Inlet Temp (from TP-3), ^oF	101	101
Total Flow Rate (from TP-3), lb/hr	2240.6	2201
Simulated Heat Load (from TP-3), BTU/hr	34,200	33,600

TEST RESULTS

	PREDICTED	ACTUAL
• TEST POINT 3:		
Temperature @ Location Y, ^oF	93	101
Heat Rejection to Location Y, BTU/hr		24,524
• TEST POINT 20:		
Main Outlet Temperature, ^oF	42.5-45.8	54.2-57.4
Heat Rejection, BTU/hr		25,987-23,721

TABLE 8 (Cont'd)

TEST GROUP 1.3

	PREDICTED	ACTUAL
• Total Heat Rejected, BTU/hr (TP 3 and 20)	56,193-54,839	50,511-48,245

REMARKS

- Heat Load Simulation was good.
- Higher than desired absorbed fluxes caused higher than predicted system outlet temperatures.
- Mix temperature varies less than 5°F with cyclic environments, while individual outlet segments vary 10-15°F.

TABLE 9

TEST GROUP 1.4 SUMMARY

TEST CONDITIONS

	DESIRED	ACTUAL
• TEST POINT 4		
Average Environment, BTU/hr-ft^2	130	135.8
Inlet Temperature, ^oF	116.2	116
Total Flow Rate, lb/hr	1100	1119.4
Simulated Heat Load, BTU/hr	42,000	42,400
• TEST POINT 8		
Average Environment on Cargo Bay Panels (1, 3, 5, & 7) BTU/hr-ft^2	130	140.1
Average Transient Environment on Cavity Panels, BTU/hr-ft^2		
Panel 2	0-60	15 3-56.6
Panel 4	0-60	15.9-58.0
Inlet Temperature (from TP4)^oF	96	95
Total Flow (From TP-4) lb/hr	1119.4	1108.
Simulated Heat Load (from TP-4) BTU/hr	31,200	30,400

TEST RESULTS

	PREDICTED	ACTUAL
o TEST POINT 4		
Temperature @ "X", °F	92.3	95
Heat Rejection to Location X, BTU/hr		11,446
o TEST POINT 8		
Main Outlet Temperature, °F	25.6-56.3	42.7-62.5
Heat Rejection, BTU/hr		28,204-18,078
o TOTAL HEAT REJECTED, BTU/hr		39,650-29,524

REMARKS

- o Heat load simulation was good.
- o Higher than desired absorbed fluxes caused higher than predicted system outlet temperatures.

TABLE 10

TEST GROUP 1.5 SUMMARY

TEST CONDITIONS	DESIRED	ACTUAL	
TEST POINT 10			
Average Environment, BTU/hr-ft^2	30	35.6	
Inlet Temperature, ^oF	162.4	Main = 163.6	Prime=161.8
Total Flow Rate, lb/hr	550	551	
Simulated Heat Load, BTU/hr	70,000	70,283	
TEST POINT 11			
Average Environment, BTU/hr-ft^2-Panels 1,3,5,7	30	27.5	
Average Envir. Panels 2 & 4	216	181.4	
Inlet Temp. (from TP10) ^oF	T_M= 16.3 T_P= 154.3	T_M= 15.2 T_P= 132.5	
Total Flow (from TP 10) lb/hr	1102	1107	
Simulated Heat Load, BTU/hr	24507	-21[illegible]0	
TEST POINT 12			
Average Environment, Panels 1, 3,5, 7 BTU/hr-ft^2	30	31.55	
Average Environment, Panels 2 & 4	20	7.65	
Inlet Temp. (from TP10)^oF	T_M= 16.3 T_P= 154.3	T_M= 15.8 T_P= 152.5	
Total Flow (from TP10) lb/hr	1102	1109	
Simulated Heat Load, BTU/hr	24507	23800	
TEST POINT 14			
Average Environment, Panels 1, 3, 5 & 7	30	30	
Average Environment, Panels 2 & 4	216	180	
Average Environment, Panels 6 & 8	20	30	
Inlet Temp. (from Y TP10)^oF	T_M= 16.4 T_P=152.4	T_M= 18.4 T_P= 152.4	
Total Flow (from TP10) lb/hr	2204	2241	
Simulated Heat Load, BTU/hr	15225	7811	

TABLE 10 (CONT'D)

TEST GROUP 1.5 SUMMARY

	DESIRED	ACTUAL
TEST POINT 14A		
Average Environment Panels 1, 3, 5, 7 BTU/hr	30	25.36
Average Environment Panels 2 & 4	216-20	171.9-31.6
6 & 8	20-216	28.8-153.3
Inlet Temp., °F (From Y TP-10)	T_M = -16.4 T_P = 152.4	T_M = 20 T_P = 152
Total Flow (From TP-10)	2204	2231
Simulated Heat Load, BTU/hr	15225	11695

TEST RESULTS	PREDICTED	ACTUAL
o TEST POINT 10		
Temp @ X, °F	T_M = 11.2 T_P = 154.2	16.3 154.3
Temp @ Y, °F	T_M = 20.4 T_P = 150.2	-16.4 152.4
Heat Rejection to Location X, BTU/hr		22,479(1/2 of system)
Heat Rejection to Location Y, BTU/hr		55,000
o TEST POINT 11		
Outlet Temp., °F	46.6 105.	34.3 98.
Heat Rejection, BTU/hr		-2150(1/2 of system)
o Total Heat Rejected by TP-10,11	20,518	20,329(Hot Cavity)
o TEST POINT 12		
Outlet Temp., °F	-75.9 141.5	-65. 144
Heat Rejection, BTU/hr		12,192(1/2 of system)
o Total Heat Rejected by TP-10,12	35,675	34,671(Cold Cavity)
o Total System Heat Rejection TP-10,11 + TP-10,12		55,000(Full System)
o TEST POINT 14		
Outlet Temp, °F	T_M = 6.2 T_P = 134.6	13.1 133.3
Heat Rejection, BTU/hr		4505
o Total Heat Rejected TP-10,14	59,458	59,505

TABLE 10 (CONT'D)

TEST GROUP 1.5 SUMMARY

	ACTUAL
o TEST POINT 14A	
Outlet Temperature, °F	-4.9 → 8.7 139.2 143
Heat Rejection, BTU/hr	6275 - 9520
o TOTAL HEAT REJECTED BY TP-10, 14A	61,275-64,520

REMARKS

- Heat load simulation for TP-11 and TP-14 was not adequate because the main/prime flow split did not match TP-10. TP-11 had the majority of flow through the main system.
- Flow split between main and prime for TP-10 was based on pre-test analyses to match flow split in TP-12.
- Environment simulation for sun in cavity was low.

TABLE 11

TEST GROUP 1.6 SUMMARY

TEST CONDITIONS	DESIRED	ACTUAL
• TEST POINT 17		
Average Environment, BTU/hr-ft^2	20	24.6
Inlet Temperature, ^{o}F	53	T_M= 55.3
		T_P= 53.2
Total Flow Rate, lb/hr	550	566
Simulated Heat Load, BTU/hr	7000	7358
• TEST POINT 17A		
Average Environment on Panels 1,3,5,7, BTU/hr-ft^2	20	29.7
Average Environment on panels 2 & 4	0	4.2
Inlet Temperature, ^{o}F	T_M= 82.2	51.6
	T_P= 51.1	52.7
Total Flow Rate, lb/hr	1132	1180.6
Simulated Heat Load, BTU/hr	4008	7340
• TEST POINT 16		
Average Environment on Panels 1, 3, 5, 7,BTU/hr-ft^2	20	20.1
Average Cyclic Environment on Panels		
2 & 4	70-20	56-29
6 & 8	20-70	32.75-59
Inlet Temp, ^{o}F	T_M= 49.2	-18.7
	T_P= 46.9	51.6
Total Flow	2264	2224
Simulated Heat Load, BTU/hr	2[illegible]69	4467

TABLE 11 (CONT'D)

TEST GROUP 1.6 SUMMARY

TEST RESULTS	PREDICTED	ACTUAL
o TEST POINT 17		
Temperature at X, °F	T_M = -121	-84.
	T_P = 50.7	47.9
Temperature at Y, °F		-91
		46.9
Heat Rejection to Location X, BTU/hr		5100
Heat Rejection to Location Y, BTU/hr		5740
o TEST POINT 17A		
Outlet Temp., °F		-152.3
		49.
Heat Rejection, BTU/hr		3160
o Total Heat Rejected by 17 and 17A		8260
o TEST POINT 16		
Outlet Temp., °F		- 37.8 → -40
		45.3 → 45.8
Heat Rejection, BTU/hr		3726 - 3555
o Total Heat Rejected by 17 and 16		9466 - 9295

REMARKS

- Pre-Test predictions for test points 17A (β configuration) and 16 (alpha) were not made under the conditions of the test.
- Heat load simulation for TP-17A and 16 was not good.
- Environment simulation was good.

TABLE 12
TEST GROUP 1.7 SUMMARY

TEST CONDITIONS

	Desired	Actual
• TEST POINT 10		
Average Environment, BTU/hr-ft^2	20	35.6
Inlet Temp., ^oF	162.4	T_M= 163.6
		T_P= 161.8
Total Flow Rate, lb/hr	550	551
Simulated Heat oad, BTU/hr	70,000	70,283
• TEST POINT 18		
Average Environment on Panels 1, 3,5,7, (BTU/hr-ft^2)	20	28.35
Average Environment on Panels 2 & 4, BTU/hr-ft^2	0	6.8
Inlet Temp., ^oF	T_M= 16.3	15.2
	T_P= 154.3	154.3
Total Flow, lb/hr	1102	1110
Simulated Heat Load, BTU/hr	24507	26311

TEST RESULTS

	Predicted	Actual
• TEST POINT 10	T_M= 11.95	16.3
Temperature @ location "X", ^oF	T_P= 152.3	154.3
• TEST POINT 18		
Outlet Temp, ^oF	-	- 69.3
		145
• Total Heat Rejected, TP-10 and 18, BTU/hr	-	69067

REMARKS

- Test Point 10 used for sun on belly - Average Environments for top of Cargo Bay for Sun on Cavity (approximately 30 BTU/hr-ft^2) are similar to Sun on Belly (approximately 20 BTU/hr-ft^2).

TABLE 13 TWO SIDED RADIATION TEST SUMMARY

Test Group	Test Point	TEST CONDITIONS: AVERAGE ENVIRONMENTS BTU/HR-FT2 DESIRED PANELS 1-4	DESIRED PANELS 5-8	ACTUAL PANELS 1-4	ACTUAL PANELS 5-8	INLET TEMPERATURE °F Desired	INLET TEMPERATURE °F Actual	TOTAL FLOW LB/HR Desired	TOTAL FLOW LB/HR Actual	SIMULATED HEAT LOAD BTU/HR Desired	SIMULATED HEAT LOAD BTU/HR Actual	TEST RESULTS: OUTLET TEMPERATURES °F Predicted	OUTLET TEMPERATURES °F Actual	TOTAL HEAT REJECTED BTU/HR Predicted	TOTAL HEAT REJECTED BTU/HR Actual
2.1	21	160	160	160.79	160.79	162.4	163.2	2200	2212	70K	69722	T_m = 74 T_p = 99	78 81	51670	49426
	22	133-158	171-130	32.4-161.6	170.3 - 128.3	162.4	162.7	2200	2201	70K	69060	T_m = 66.8 → 70.6 T_p = 99.5 → 101.1	71 → 74 71 → 72	55570 53529	52931 51196
	23	133-158	171-130	31 - 159.4	169 - 128.3	142.1	141.3	2200	2212	57.7K	56674	60.8 → 64.7 86.7 → 88	64.7 → 67.9 67.9 → 65.8	46473 44363	43289 41420
	24	133-158	171-130	25 - 155.2	166 - 125.5	116.2	115.5	2200	2214	42K	41925	53.1 → 57.2 71.2 → 72.7	55.3 → 57.4 59.5 → 58.4	35344 33135	33508 32339
	25	133-158	171-130	27 - 152.3	165.3 - 124.8	96.1	95.3	2200	2202	31K	30400	47 → 51.2 60.1 → 61.7	49 → 52.1 54.2 → 55.3	27104 24850	25229 23552
2.2	26	174	70	168.8	67.3	116.2	117.3	2200	2201	42K	42667	40.9 57.8	44.8 49	41910	39990
	27	174	70	171.5	67.2	162.4	164.9	2200	2227	70K	71517	55.5 85.2	59.5 57.4	61736	61255
	28	174	70	167	58.5	53	T_m=52.4 T_p=45.1	2200	2238	7K	3499	0.2 51.1	8.7 46.9	7500	3375
2.3	29	22-40	40-22	1.5-39.4	36.85-25.4	53	T_m=50.0 T_p=46.3	2200	2206	7K	2966	-132.3 → -126.5 49.2 → 49.2	-107.9 → -101.9 42.7 → 42.7	6987 6837	4163 4354
2.4	61	59.5 - 171.5	59.5 - 171.5	54.7 - 169.4	57.0 - 167.5	162.4	163.6	2200	2214	70K	70830		14.2 → 75 145 → 75		51782 70830
	63	23.3 - 156.4	23.3 - 156.3	31.9 - 151.5	31.7 - 151.5	162.4	164.6	2200	2204	70K	70864		-4.9 → 73.0 150.6 → 111.0		53100 70864
	64	51.4 - 171.5	17.4 - 73.2	49.7 - 170.5	31.8 - 71.1	162.4	162.7	2200	2212	70K	70024		0.8 → 57.0 147.8 → 121.0		60678 70024

TABLE 14

SUMMARY OF SET POINT CHANGES

(TWO-SIDED RADIATION)

TEST GROUP	TEST POINT	SET POINT (^{o}F)	AVERAGE ENV. ($BTU/HR\ FT^2$)	INLET TEMP (^{o}F) MAIN	INLET TEMP (^{o}F) PRIME	FLOW RATE (LB/HR) MAIN	FLOW RATE (LB/HR) PRIME	OUTLET TEMP (^{o}F) MAIN	OUTLET TEMP (^{o}F) PRIME	OUTLET TEMP (^{o}F) MIXED	HEAT REJECTED (1000 BTU/HR)
2.5	57	40	3.8	59.3	53	134	1945	-137	50	40.6	7.56
	58	50	2.9	-18	52.3	5.7	2010	-125	50	50	12.78
	60	40	3.7	59.3	53	136	1919	-132	50	40.6	7.48
2.6	51	40	12.7	159	157.6	1379	884	-38	149	39.5	69.51
	52	50	7.6	113	113	647	1557	-109	109	50	35.67
2.7	52A	50	5.0	73	75	275	1881	-157	72	46.9	16.15
	52B	40	5.2	73	75	337	1881	-157	72	40.6	19.48
	52C	50	4.9	72.5	75.7	243	1984	-159	72	50	14.95
	52D	70	3.3	56	74	22.9	1958	-157	71	70	2.61
	52E	40	5.2	73	74.3	385	1868	-139	71	39.5	20.65
2.8	53	70	121.8/10.65	163.3	133.7	970	1273	-19	130	67.9	45.66
	54	40	126.6/14.1	163	155.5	1950	275	24	137	40.6	70.53
	55	50	126.4/14.2	164	162	1727	510	16	151	50	66.51
	56	70	122.7/10.5	163	134.3	957	1273	-20	130	68.9	45.44
	59	40	126.8/14.6	163.2	154	1975	266	26	135	39.5	70.50

TABLE 15

SUMMARY OF ALTERNATIVE PLUMBING TEST POINTS

TEST GROUP	TEST POINTS	CONFIGURATION	MAIN INLET TEMPERATURE (°F)	MAIN FLOWRATE (LB/HR)	AVERAGE ENVIRONMENT (BTU/HR FT2)	HEAT REJECTED (1000 BTU/HR)
3.1	32	γ	165	2223	129.8	31.9
	33	δ	164.1	2174	129.7	30.7
	45	ε	161.1	2158	128.8	29.8
	46	ε-4,7,8	162.7	2198	129.8	22.5
3.2	37	γ	52.1	1466	110.0 (top) 109.9-25.0 (cav.)	5.6
	38	δ	53.2	1466	110.7 (top) 109.8-25.1 (cav.)	6.6
	39	δ - γ	53.2	2211	110.4 (top) 111.1-25.0 (cav.)	3.4
	62	γ	53.7	14.2	2.7	6.0
3.3	48	δ	100	2130	129.1 (top) 29.6-81.1 (cav.)	23.2
	49	γ	100	2161	128.5 (top) 29.5-76.6 (cav.)	22.4
	43	γ	-14.1	149	8.35 (top) 10.1-51.4 (cav.)	5.5

TABLE 16

SUMMARY OF HEAT LOAD TRANSIENT TEST POINTS

TEST GROUP	TEST POINT	AVG. ENVIRONMENTS BTU/HR	INLET TEMP RANGE - °F	MAIN OUTLET TEMP. RANGE - °F	HEAT REJECTION RANGE-BTU/HR
3.4	47	125.4 (Panels 1-4) 7.3 (Panels 5-8)	51.6/160./50.5	-8.3/27.9/8.7	6248/67786/5654
	19	Variable (12.9-171)*	162.7/52.1/161.6	72/17.4/72	67860/6495/67596
	50	10.5 (Panels 2,3,5 & 6)	45.6/162.7	4.2/89.0	2789/43530
3.5	17A-18	26.2(Panels 1,3,5,7) 5.5(Panels 2 & 4)	47.9/154.3	-152.3/-64.2	1580/12412
	36-36A	13.5	47.9/164.6	-146.5/-22.2	2668/36049
	60 - 51	3.7/12.7	53/159	-130.5/-35.0	7178/69373

* Panels 2, 6, 7 and 8 environments not known exactly due to degraded insulation blanket configuration.

TABLE 17

SUMMARY OF SIMULATED LOW α/ε COATING TESTS

TEST GROUP	TEST POINT	FLOW CONFIGURATION	AVERAGE ENVIRONMENT (BTU/HR FT^2) PANEL	FLUX	ACTUAL AREA FT^2	SIMULATED AREA FT^2	HEAT LOAD BTU/HR	HEAT REJECTED (BTU/HR)	CALCULATED WATER BOILING REQUIRED(LB/HR)
3.6	31	γ - 1,3	2,4,5 6,7,8	58.6 52.2	432	512(half of system)	74,012	67,392	6.62
	36	γ - 1,3	2,4,5 6,7,8	4.2 3.6	432	512	5,336	5,336	-
	36A	γ - 1,3	2,4,5 6,7,8	14.8 12.1	432	512	72,098	72,098	-
3.7	2	α	1,5 2,3,4 6,7,8	60.2-65.2 38.4-78 71.1-45.7	576	682	66,803	51,265 - 54,181	14.08

TABLE 18

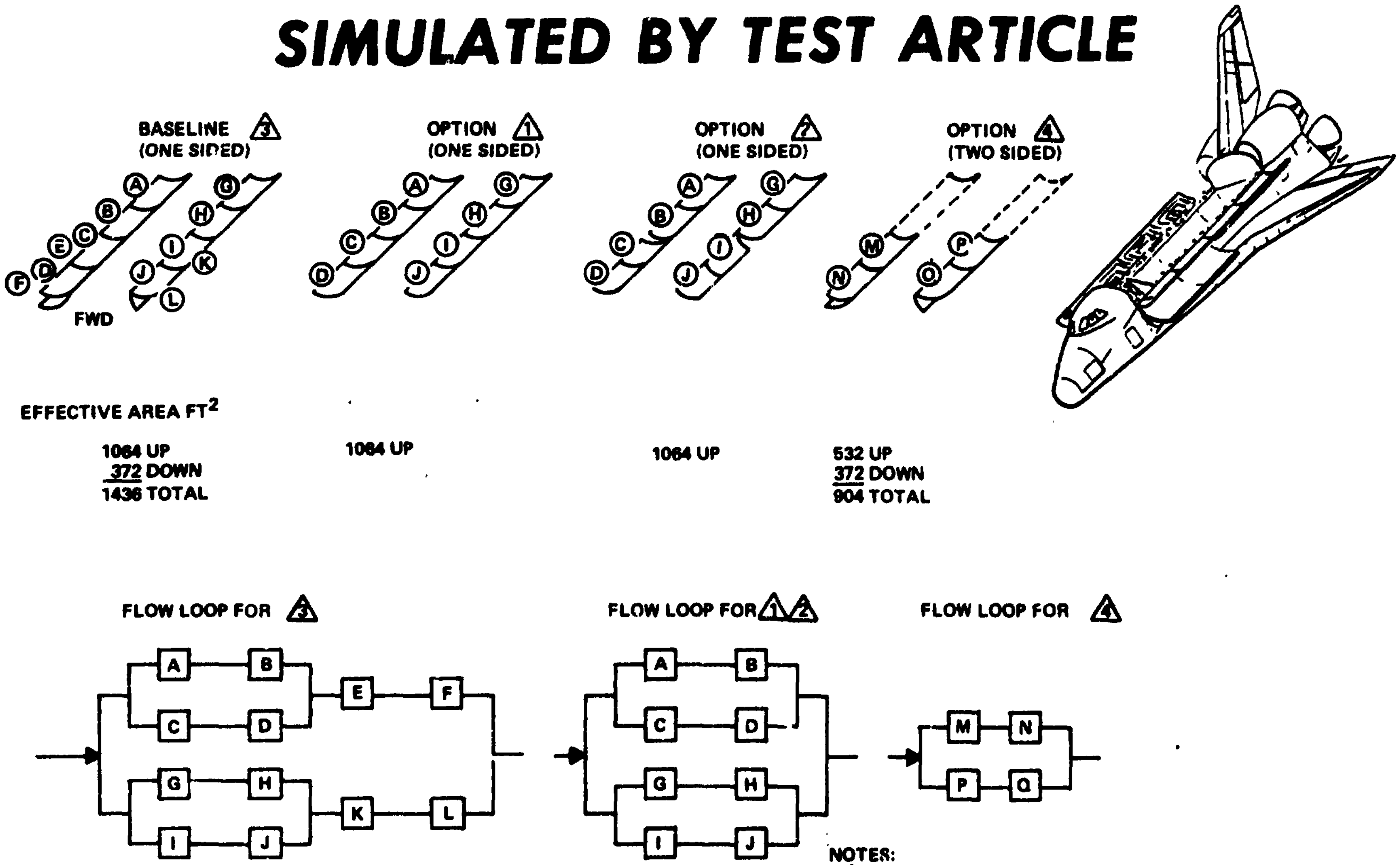
EXTRAPOLATION OF TEST DATA TO BASELINE CONFIGURATION

		TEST CONDITIONS			TEST RESULTS			SHUTTLE VEHICLE EXTRAPOLATED RESULTS		
TEST GROUP	TEST POINT	HEAT LOAD	PORTION OF SYS SIMULATED	ORBIT (SUN ON)	AVERAGE SYS. TOTAL HEAT REJ.	TOP OF CARGO BAY DOOR Q_{REJ}	CAVITY Q_{REJ}	TOP CBD Q_{REJ}	CAVITY Q_{REJ}	AVERAGE SYS TOTAL Q_{REJ}
1.1	1A,5	79.4	1/2	CB	71.8	25.0	10.9	22.4	15.5	76.6
1.2	1,5	70.5	1/2	CB	63.6	20.9	10.9	18.7	15.5	68.4
1.5	10,11 & 10,12	55.0	1/2(Each cavity tested separately)	Cavity (Const Env.)	55.0	64.6	-13.6/ 4.3	57.8	-19.4/ 6.1	44.5
	10,14	62.8	Full	Cavity (Const Env.)	58.5	66.6	-11.4/ 3.3	52.2	-16.2/ 4.7	40.7
	10,14A	61.3*	Full	Cavity (Cyclic Env.)	61.3	67.4	-10.4/ 4.3	54.6	-14.8/ 6.1	45.9

All Values In 1000 BTU/HR

* Outlet Control Point = 49°F

SHUTTLE CONFIGURATIONS SIMULATED BY TEST ARTICLE



NOTES:
△ ANALYSIS CONFIGURATION
⊗ SHUTTLE PANEL (LETTER)
EFFECTIVE PANEL AREAS FT^2

ABCDGHIJ	133 UP
EFKL	93 DOWN
MNPQ	226 (133 UP, 93 DOWN)

FIGURE 2

$\beta = 78^{\circ}$ ORBITS SIMULATED

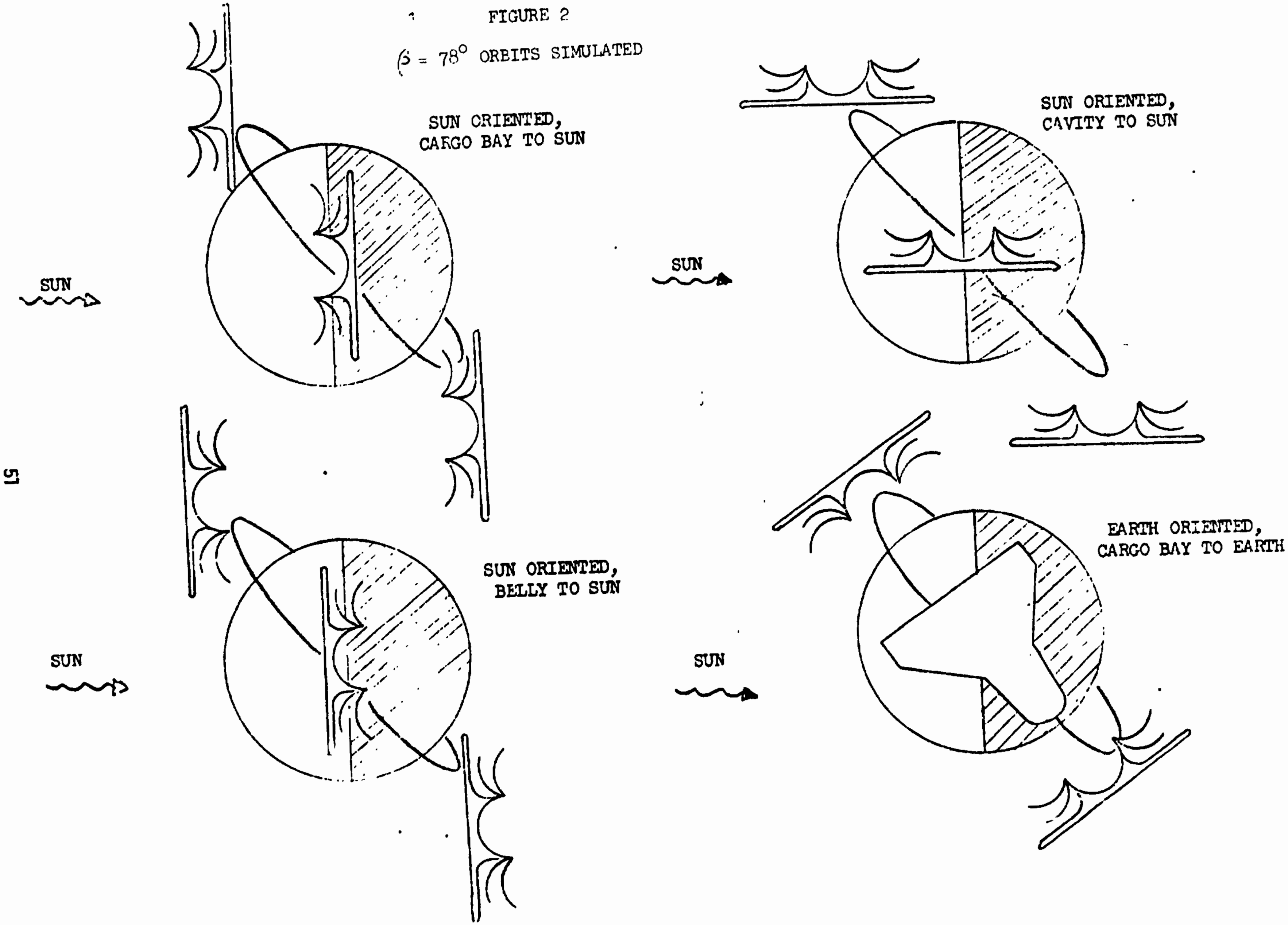
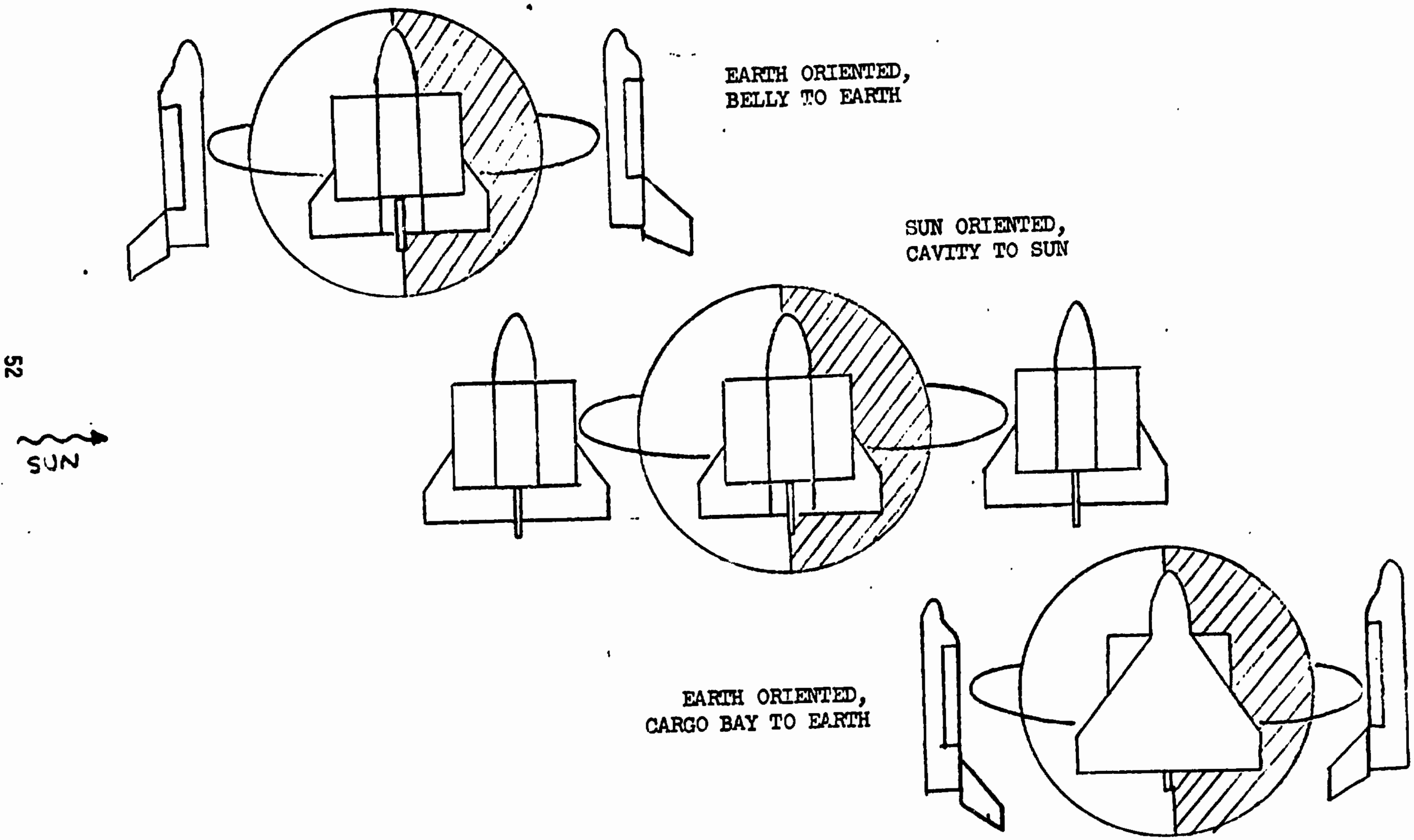


FIGURE 3

$\beta = 0^\circ$ ORBITS SIMULATED



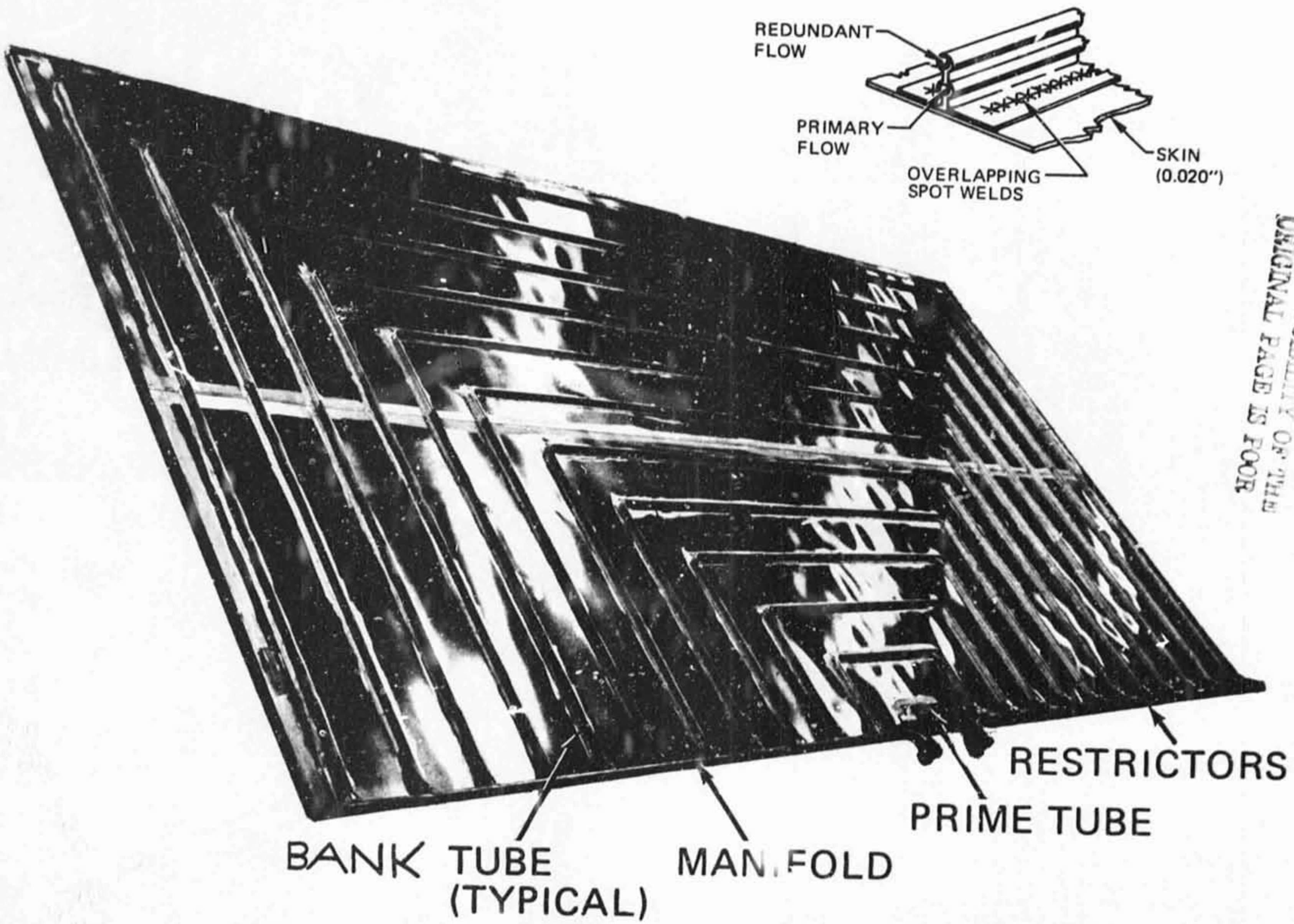


FIGURE 4

UNCOATED RADIATOR PANEL

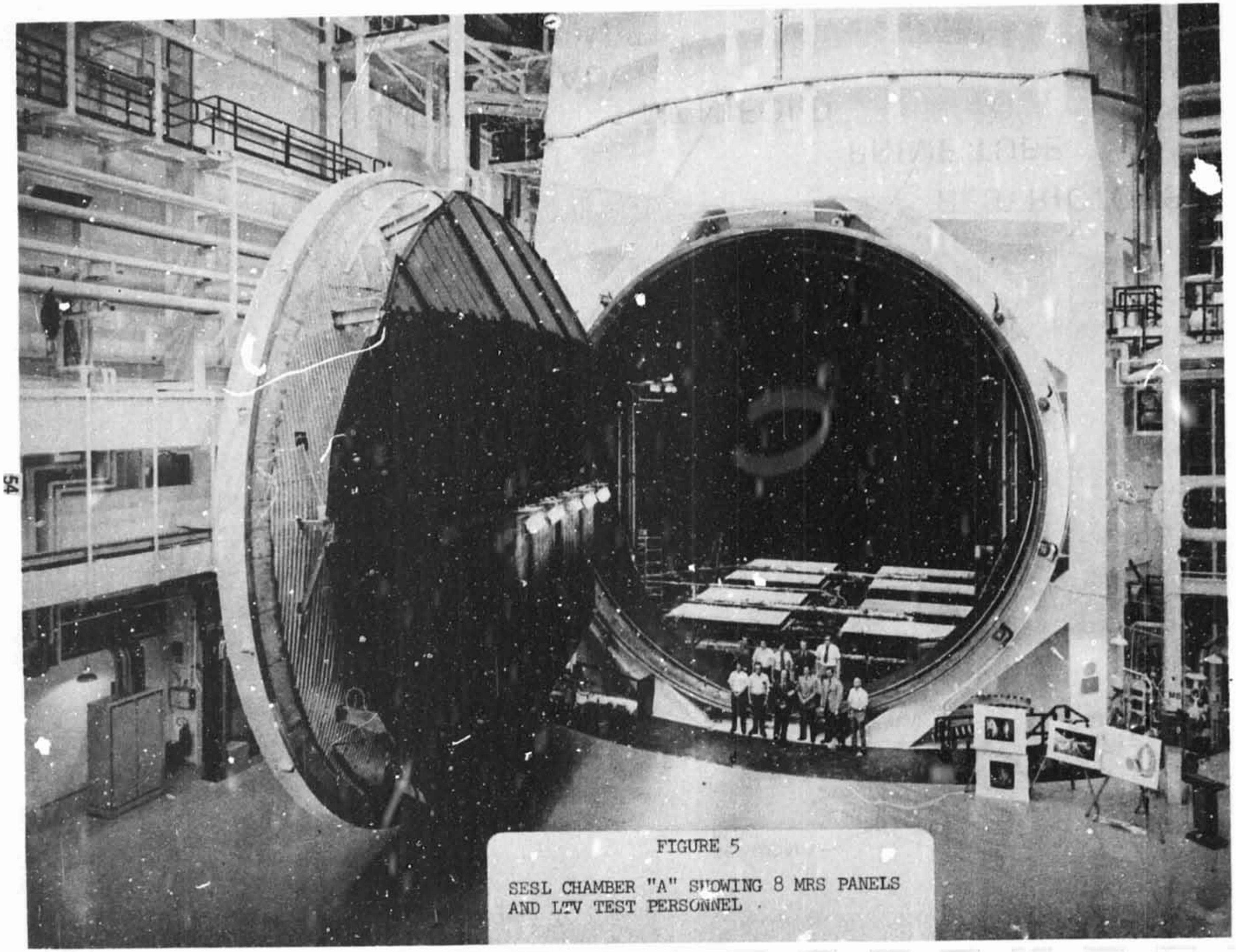


FIGURE 5

SESL CHAMBER "A" SHOWING 8 MRS PANELS
AND LTV TEST PERSONNEL

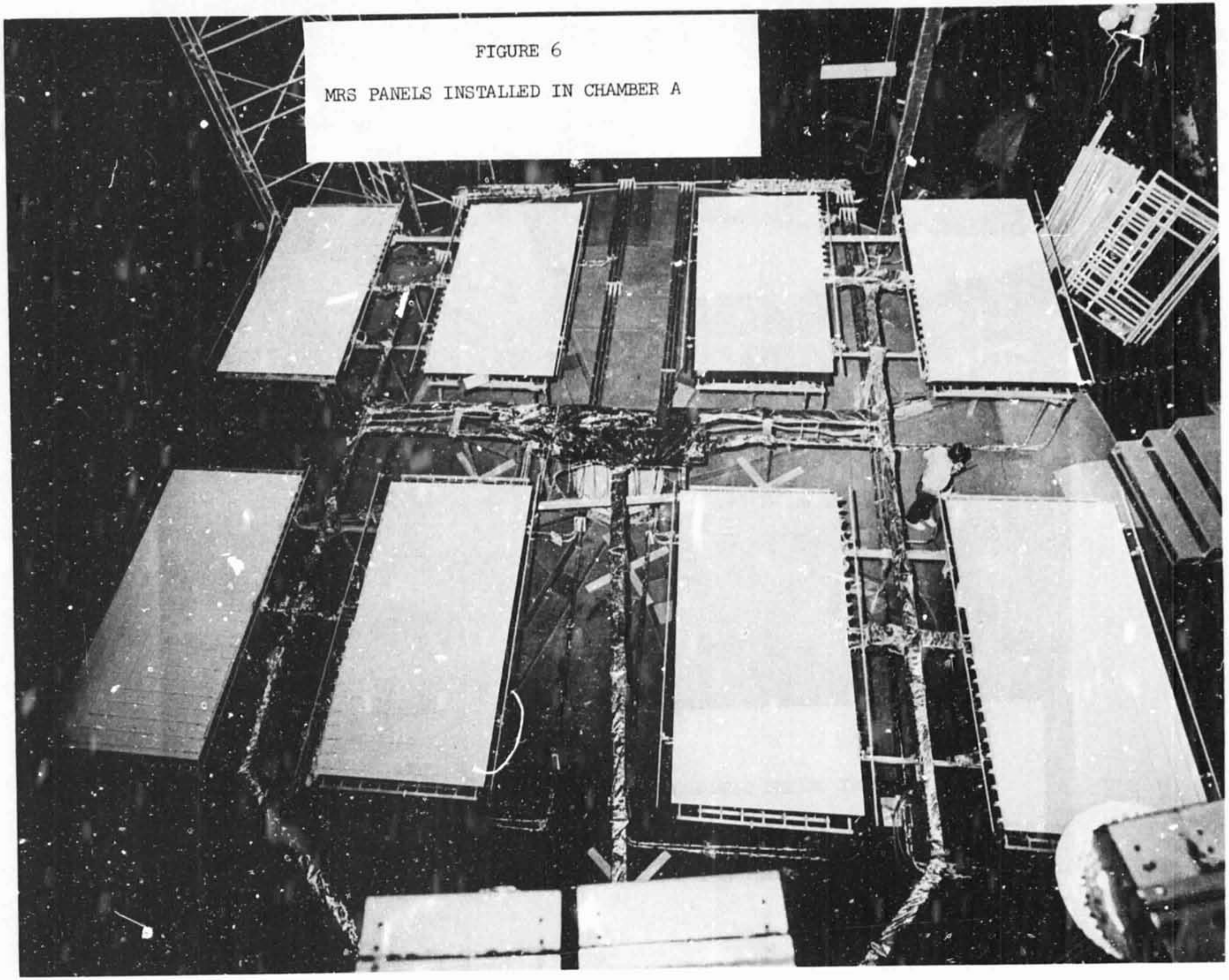


FIGURE 6

MRS PANELS INSTALLED IN CHAMBER A

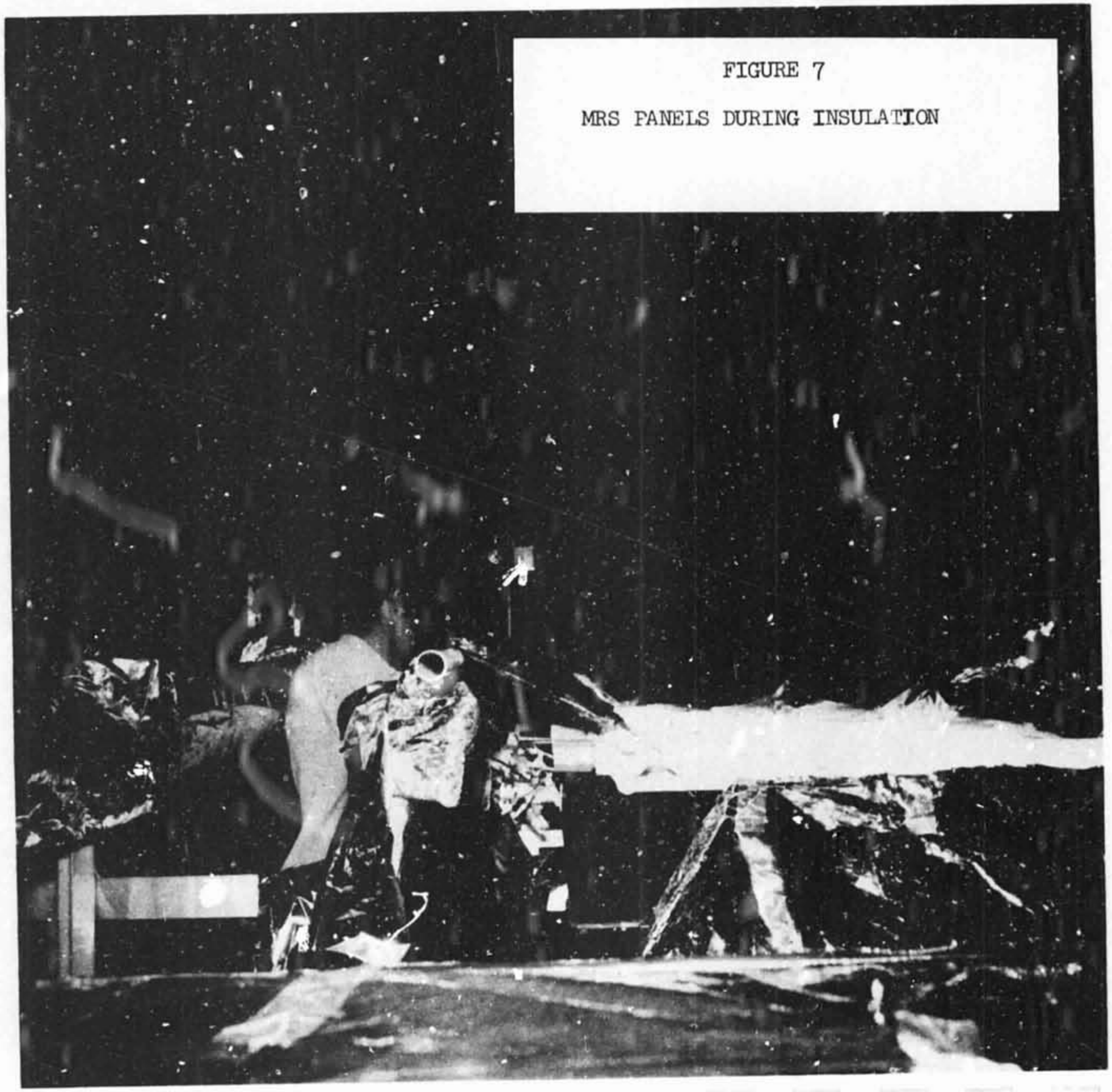


FIGURE 7

MRS PANELS DURING INSULATION

FIGURE 8

CONNECTING TUBES AND PANELS AFTER
INSULATION

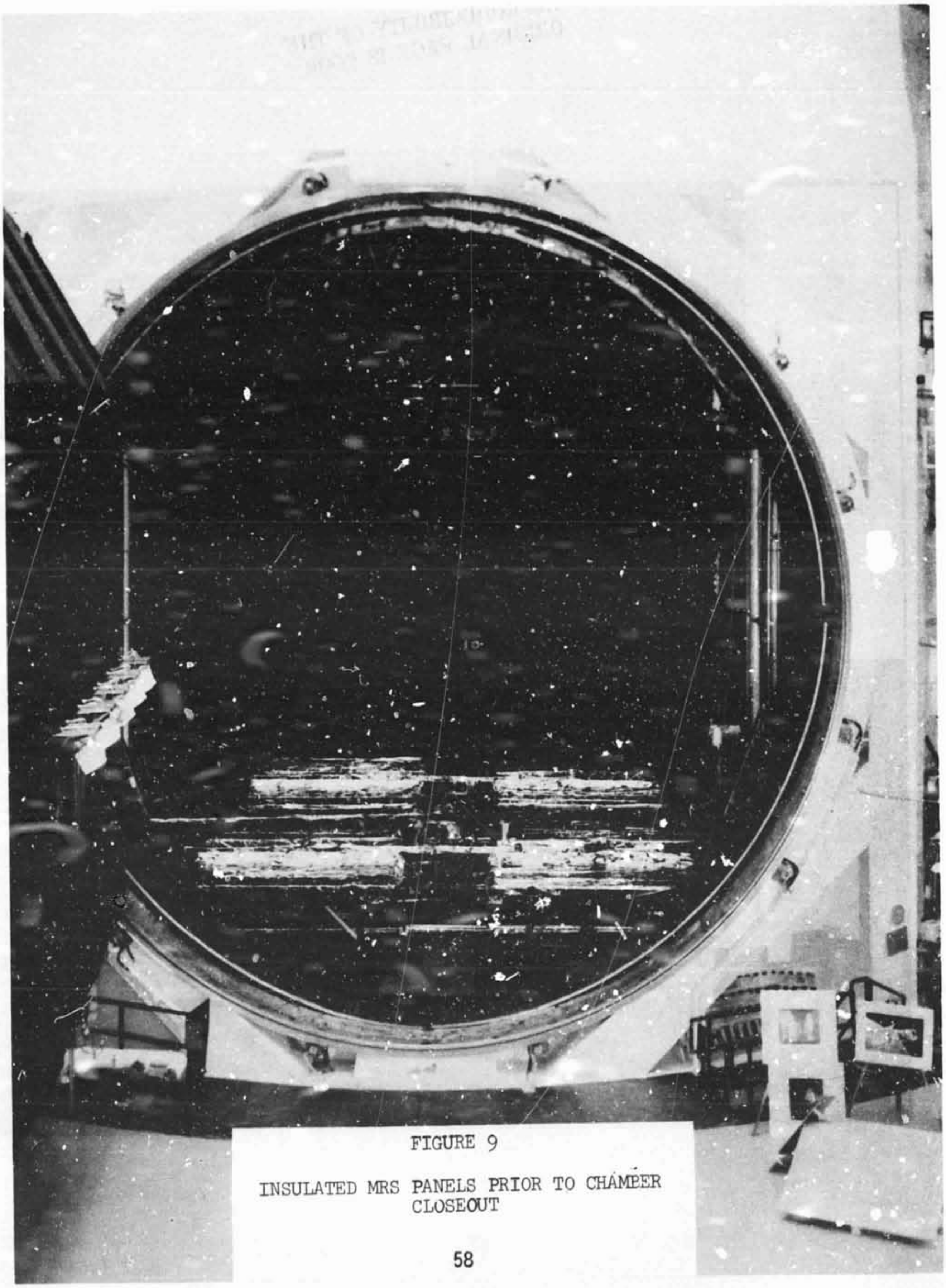
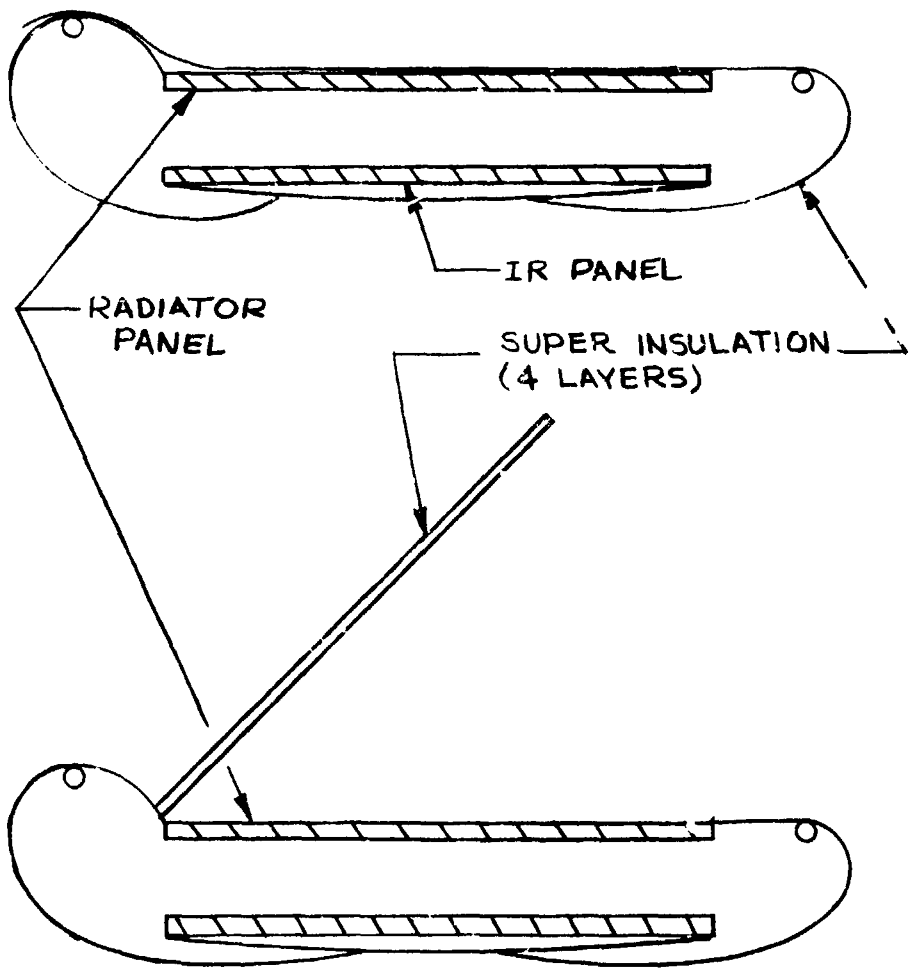


FIGURE 9

INSULATED MRS PANELS PRIOR TO CHAMBER CLOSEOUT

ONE SIDED



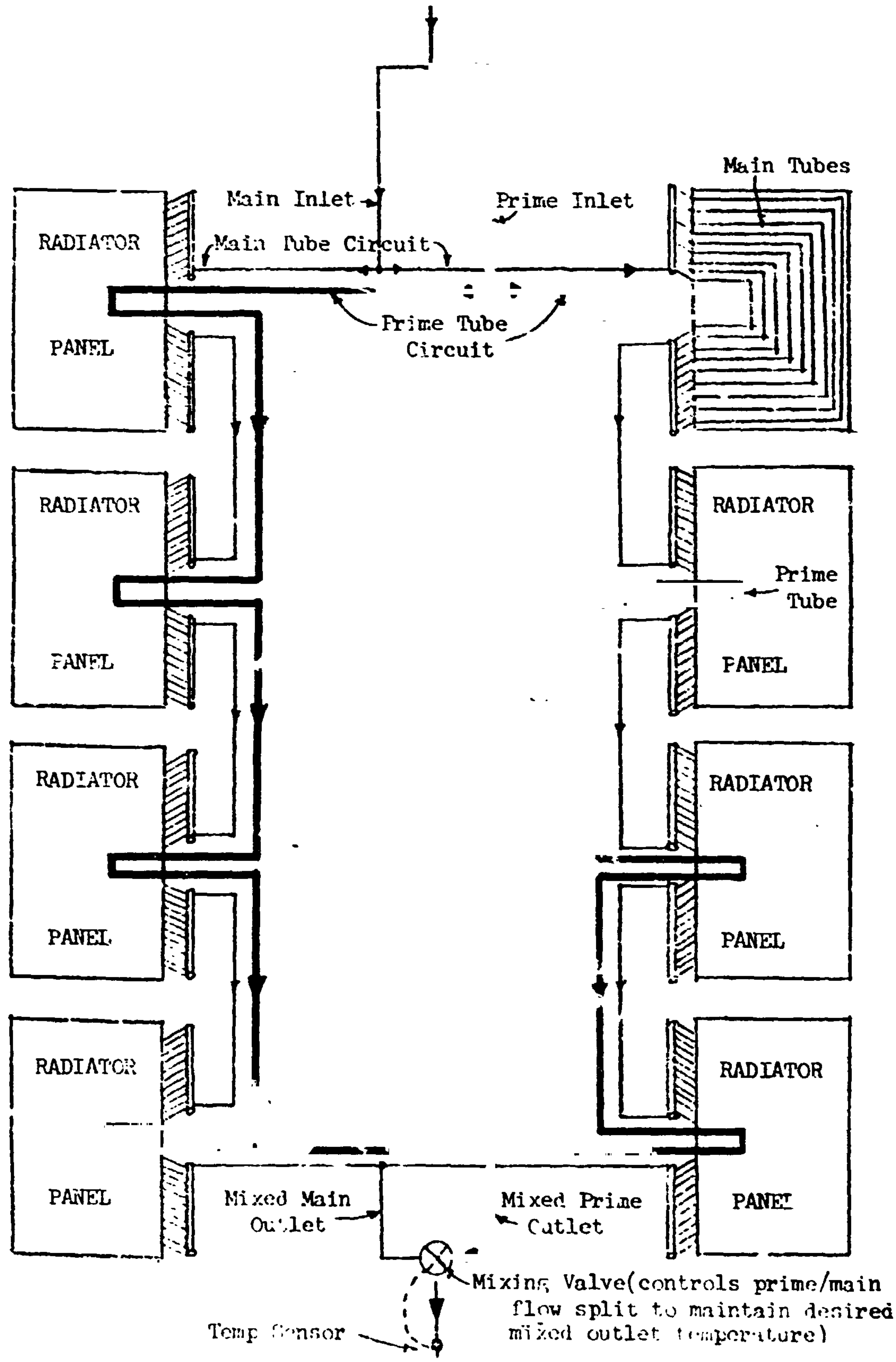
TWO SIDED

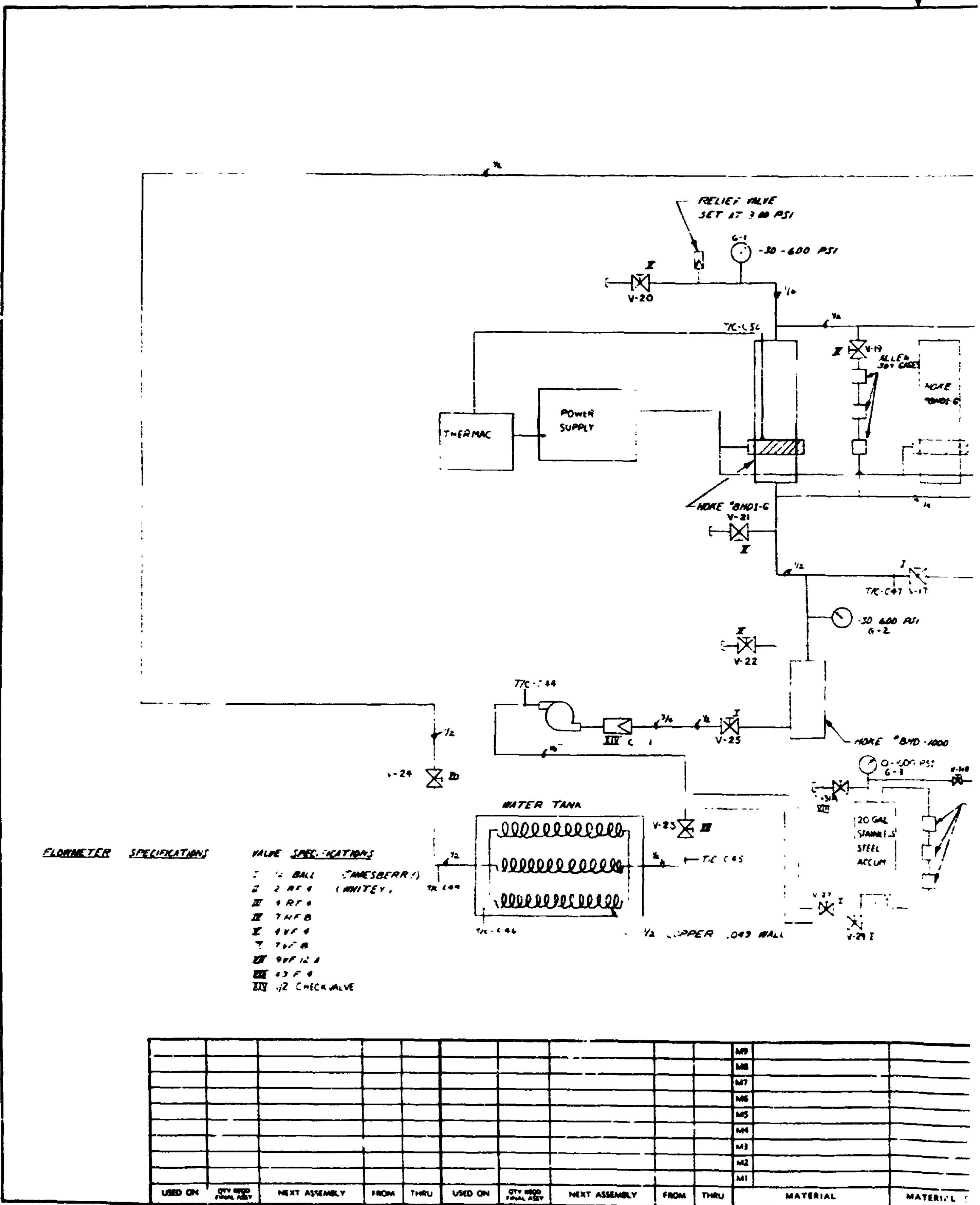
FIGURE 10

DETAIL OF INSULATION ON PANELS AND ENVIRONMENT SIMULATOR

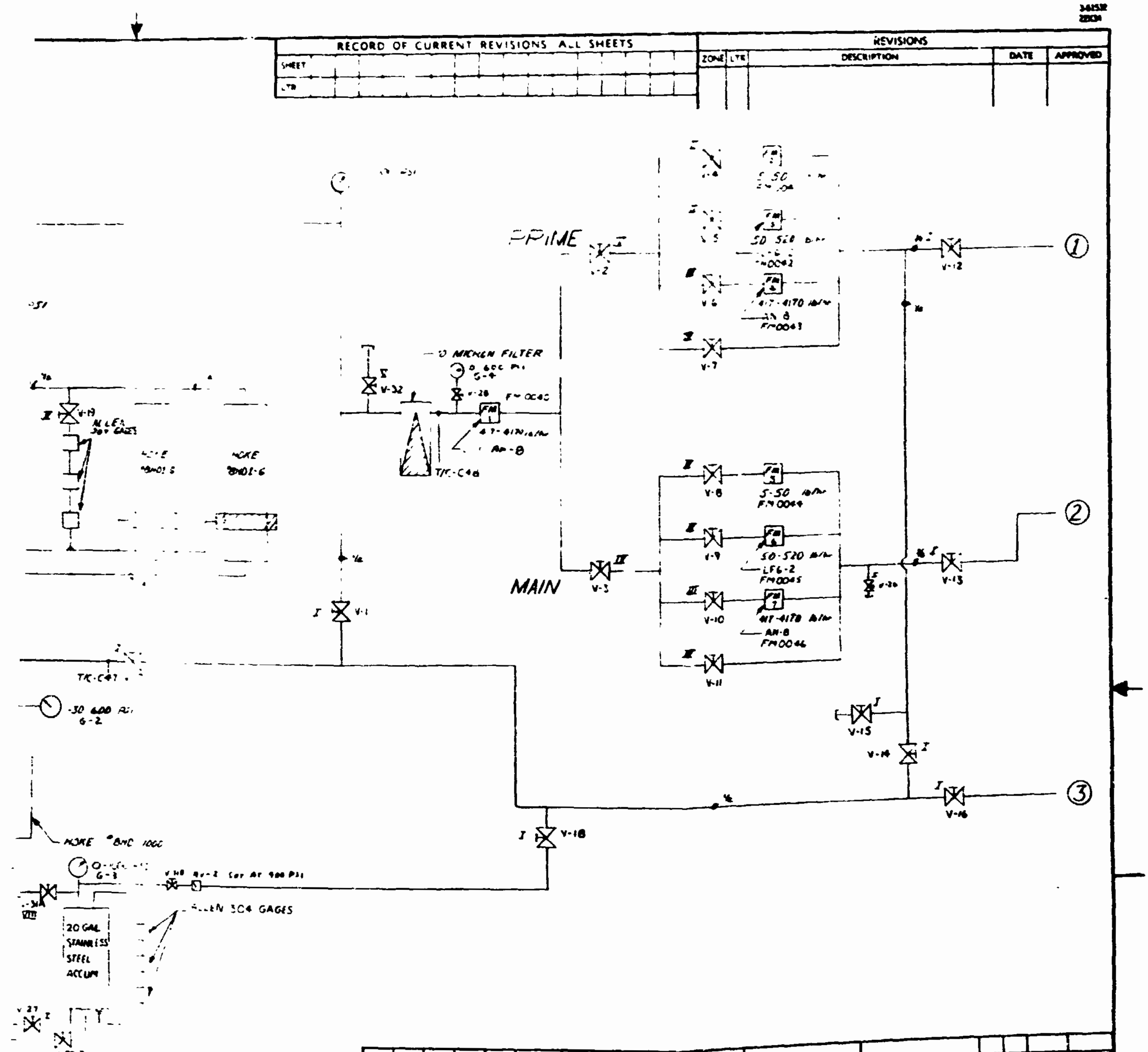
FIGURE 11

SIMPLIFIED SYSTEM SCHEMATIC, SHOWING PRIME AND MAIN TUBE RELATIONSHIPS





FOLDOUT FRAME



QTY REQD	ITEM NO	ZONE	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	UNIT WT

LIST OF MATERIAL

MATERIAL	MATERIAL SPECIFICATION	PROTECTIVE FINISH

UNLESS OTHERWISE NOTED DIMENSIONS ARE IN INCHES
LINEAR TOL: XX ± .03; XXX ± .010
ANGULAR TOL: ± 0° 30'
AND 10387 TOLERANCES ON DRILLED HOLES
ALL MACHINED SURFACES REF ANSI B46.1

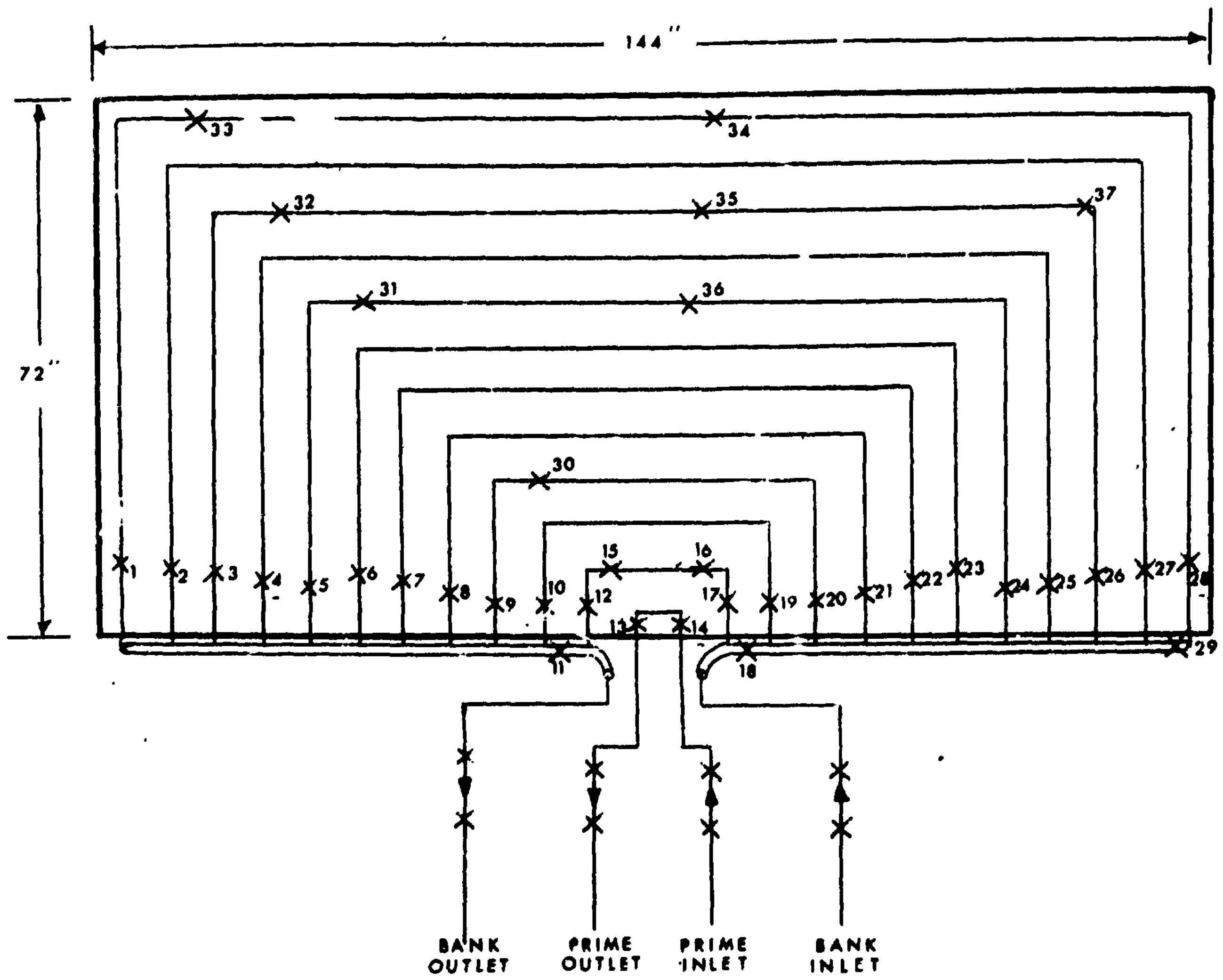
FIGURE 12
FLUID SCHEMATIC FOR FULL SCALE MODULAR RADIATOR

SIZE D | CODE IDENT NO 11813 | SK 20020
SCALE | REV LTR B | SHEET 1 OF 2

FOLDOUT FRAME 2

FIGURE 13

THERMOCOUPLE LOCATIONS ON PANEL



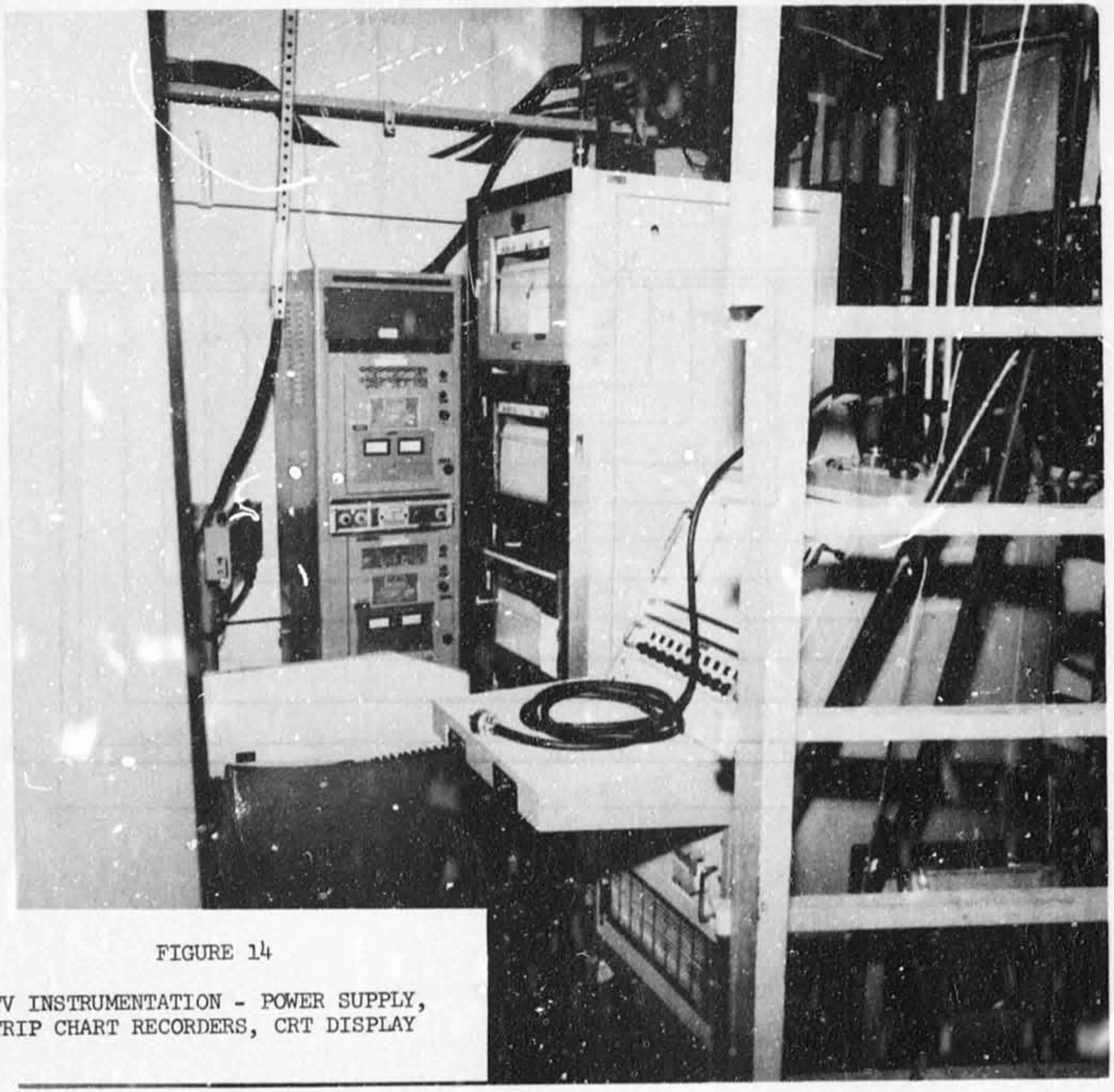


FIGURE 14

LTV INSTRUMENTATION - POWER SUPPLY, STRIP CHART RECORDERS, CRT DISPLAY

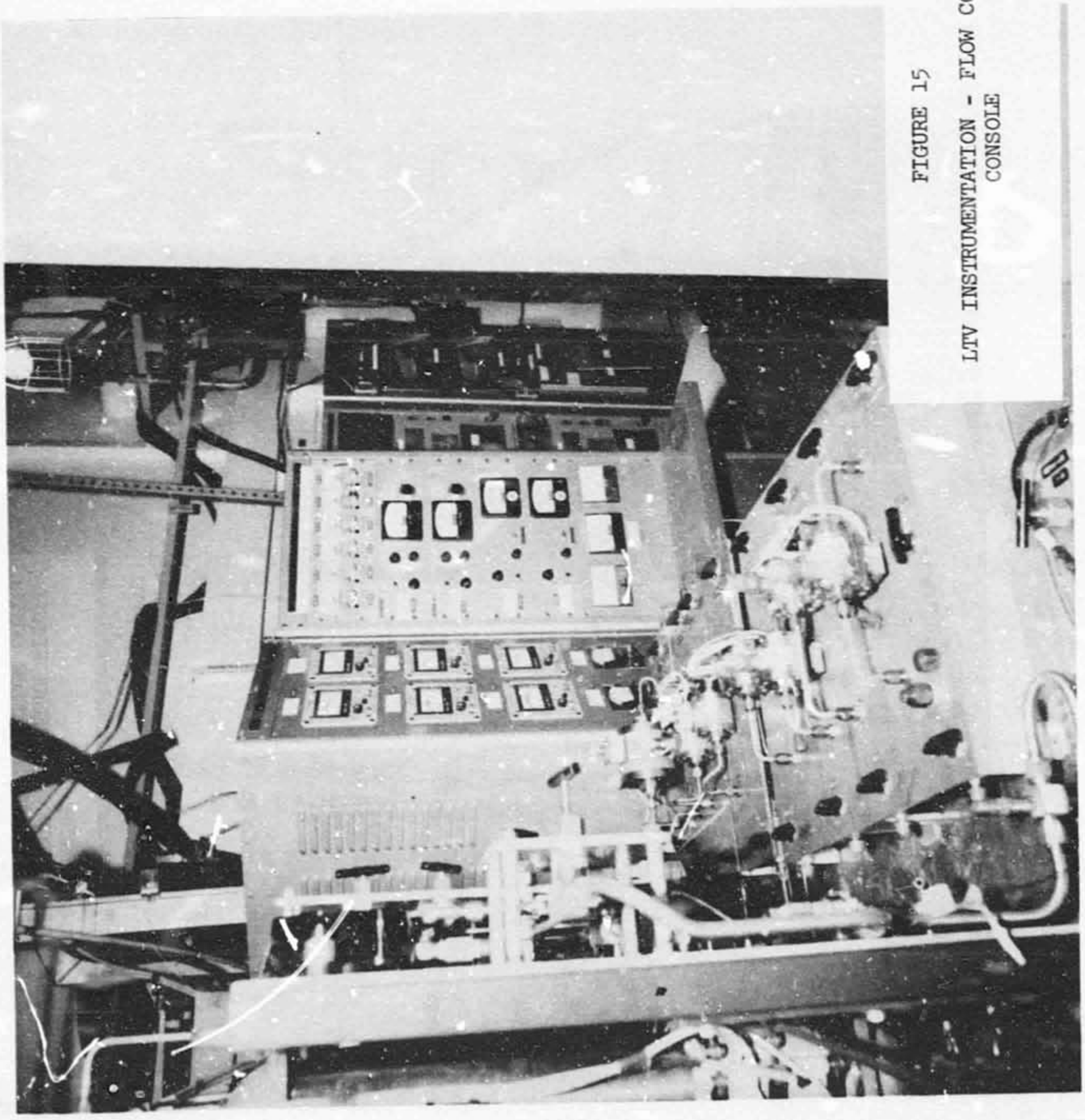


FIGURE 15

LTV INSTRUMENTATION - FLOW CONTROL CONSOLE

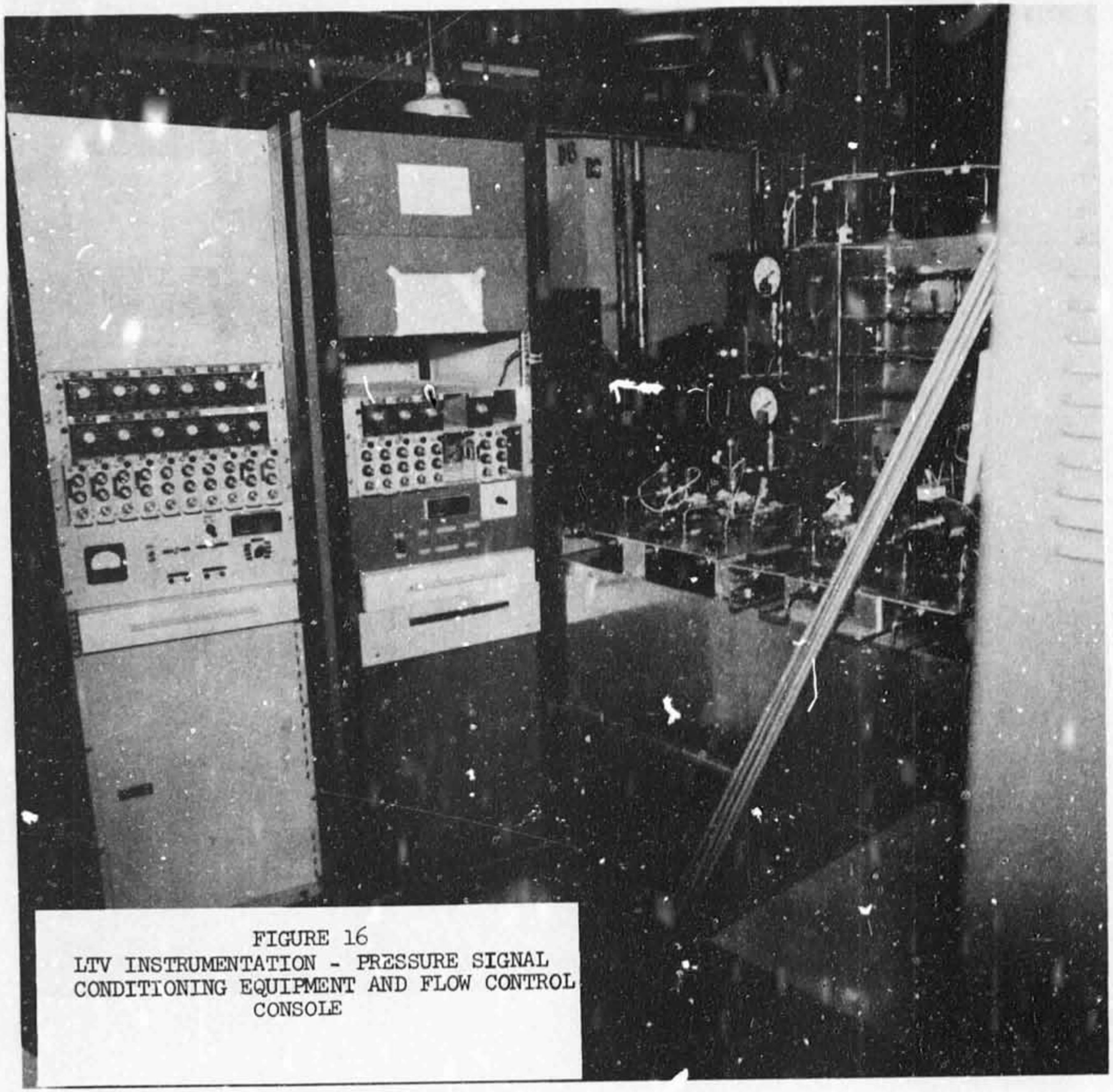


FIGURE 16
LTV INSTRUMENTATION - PRESSURE SIGNAL CONDITIONING EQUIPMENT AND FLOW CONTROL CONSOLE

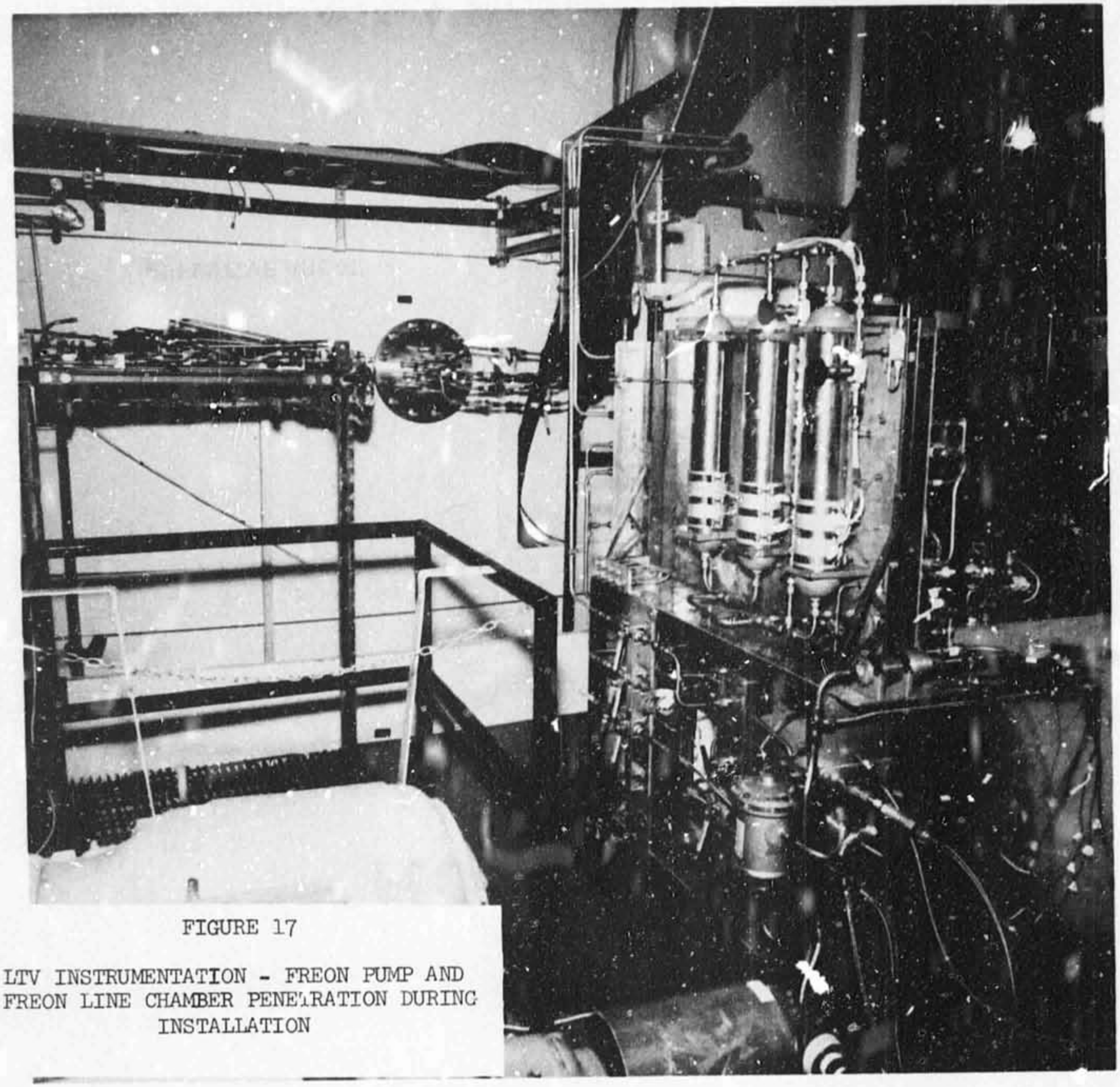
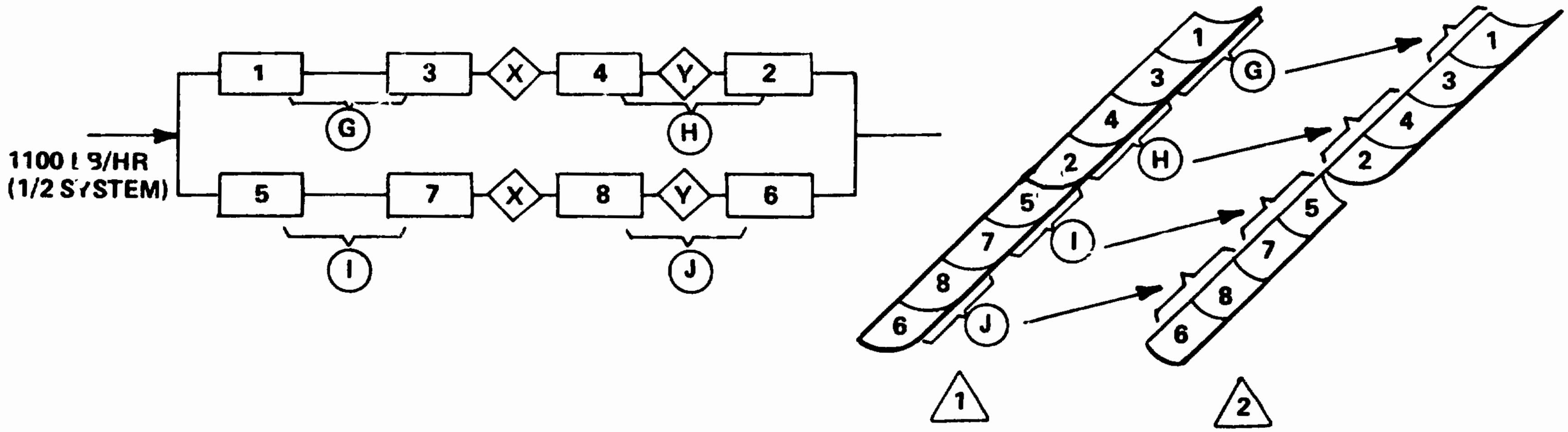


FIGURE 17

LTV INSTRUMENTATION - FREON PUMP AND FREON LINE CHAMBER PENETRATION DURING INSTALLATION

FIGURE 18

FLOW LOOP α



EFFECTIVE AREAS

TEST

$\Sigma (1) \rightarrow (8) = 8 \times 72 = 576 \text{ FT}^2$

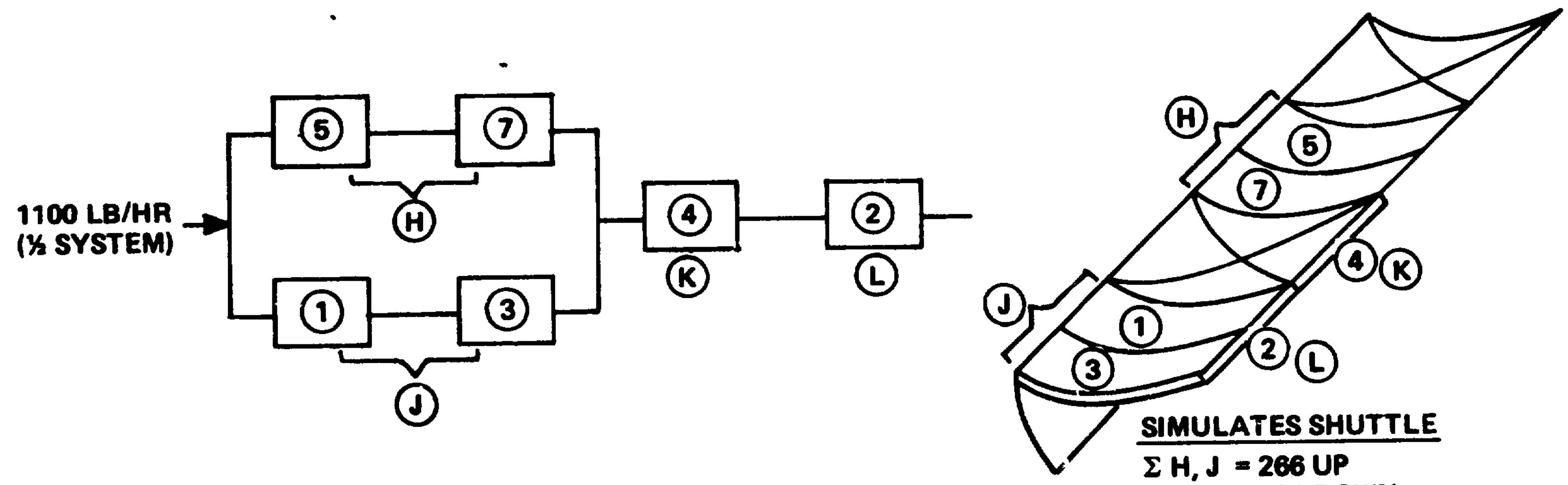
SIMULATES SHUTTLE

$\Sigma (G) \rightarrow (J) = 4 \times 133 = 532 \text{ FT}^2$

DATA FOR POINTS △X AND △Y WILL BE USED AS INLET TEMPERATURES IN OTHER TESTS

FIGURE 19

FLOW LOOP β



SIMULATES SHUTTLE

Σ H, J = 266 UP
Σ K, L = 186 DOWN
452 TOTAL

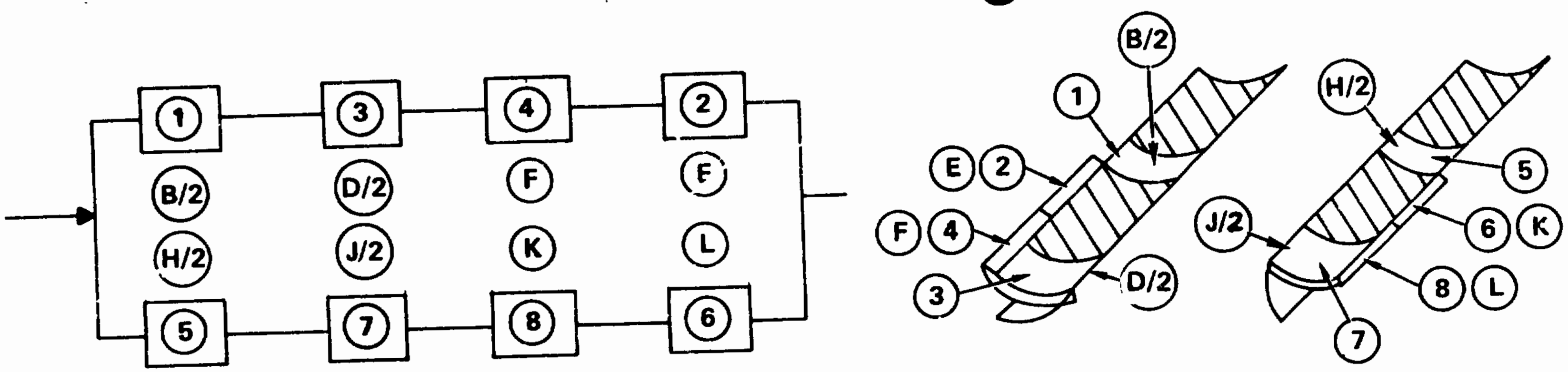
EFFECTIVE AREAS

TEST

Σ 5, 7, 6, 8 = 288 UP
Σ 4, 2 = 144 DOWN
432 TOTAL

FIGURE 20

FLOW LOOP α_3



SIMULATES SHUTTLE

Σ B/2, D/2, H/2, J/2 = 266 UP
Σ E, F, K, L = 372 DOWN
638

EFFECTIVE AREAS:

TEST

Σ 1, 3, 5, 7 = 288 UP
Σ 2, 4, 6, 8 = 288 DOWN
576

FIGURE 21
SUMMARY OF WEEK 1 FLOW CONFIGURATIONS
TO SIMULATE BASELINE SHUTTLE

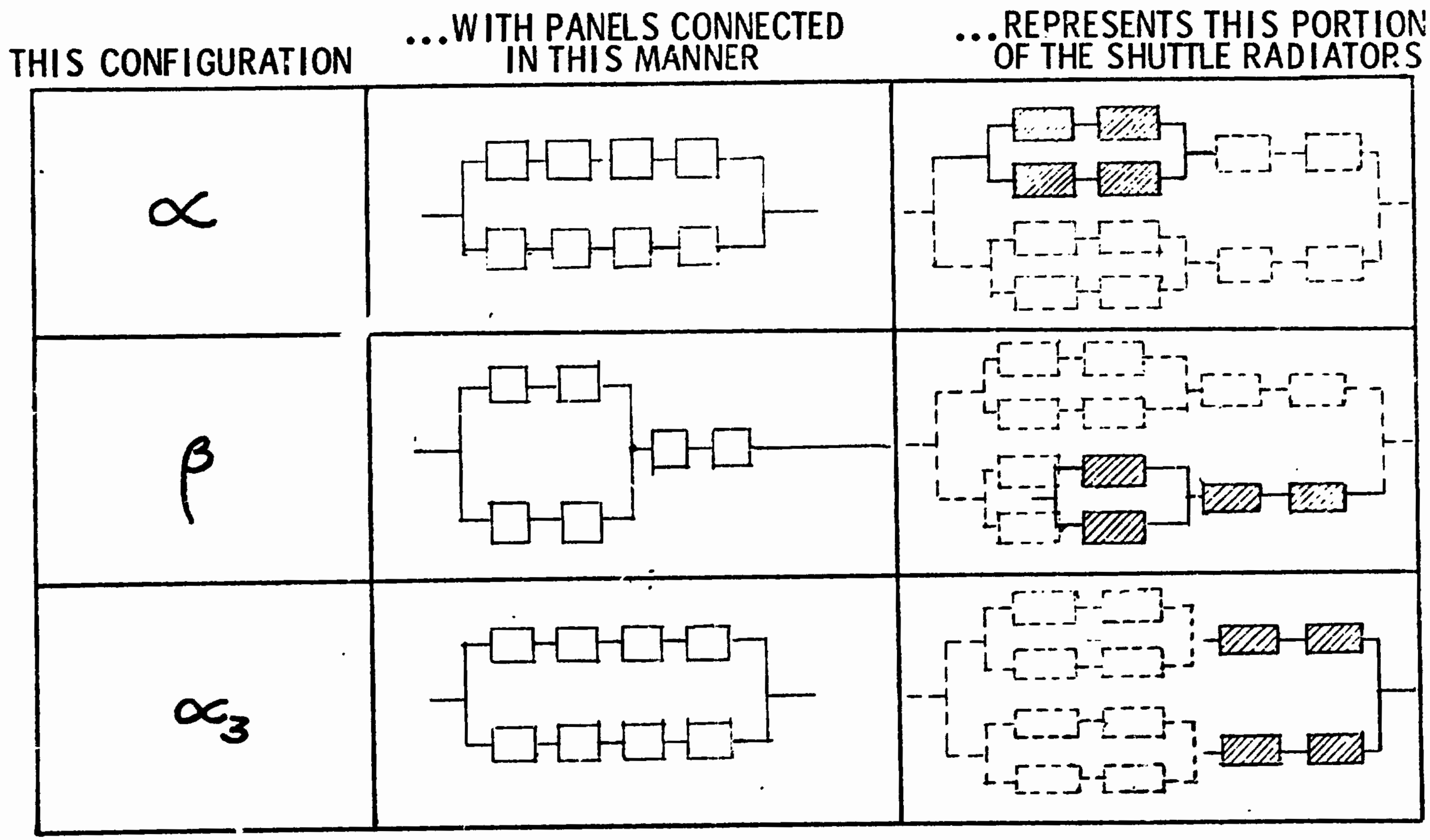
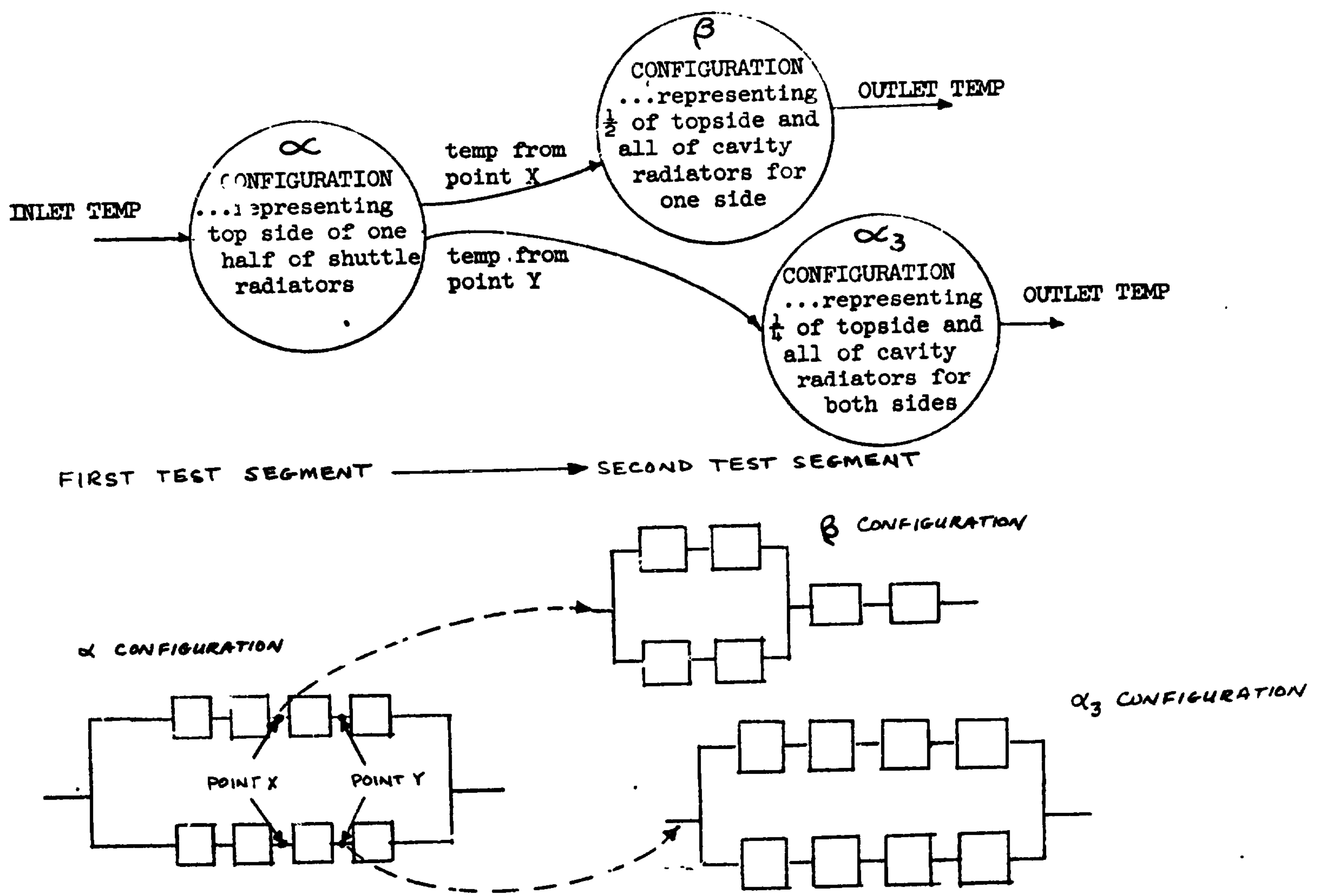


FIGURE 22

FLOW OF TESTING DURING WEEK 1



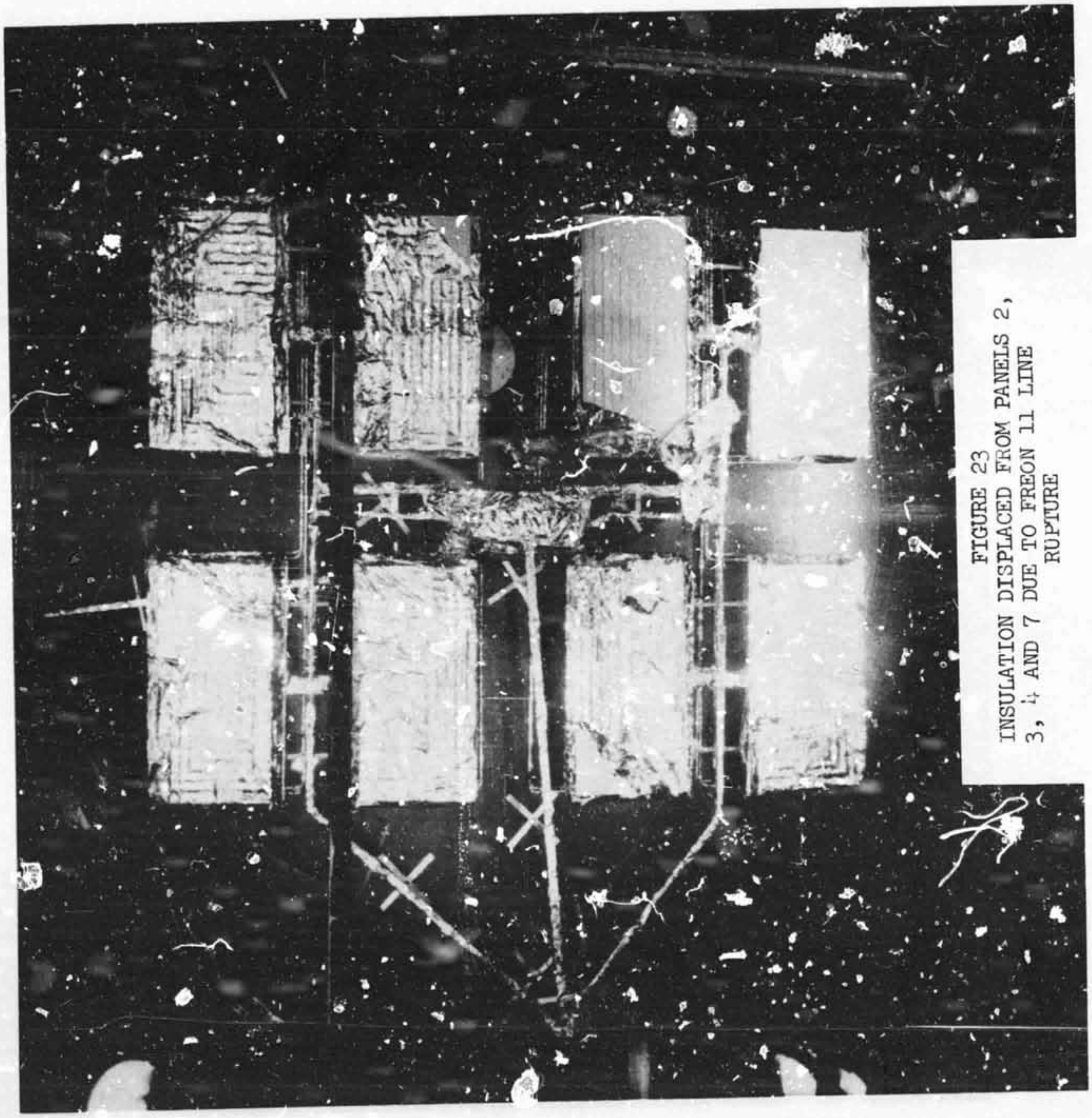


FIGURE 23
INSULATION DISPLACED FROM PANELS 2,
3, 4 AND 7 DUE TO FREON 11 LINE
RUPTURE

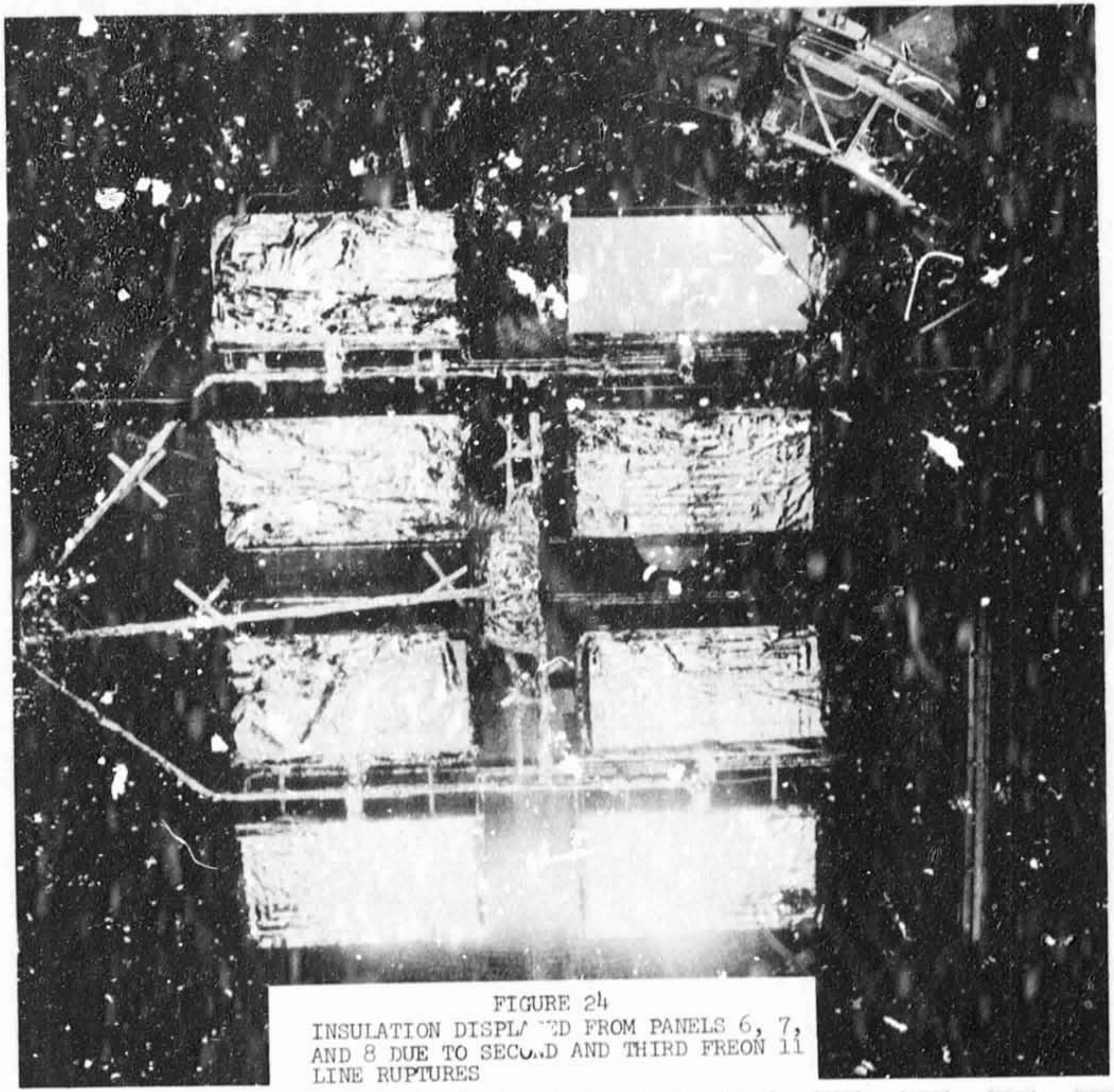
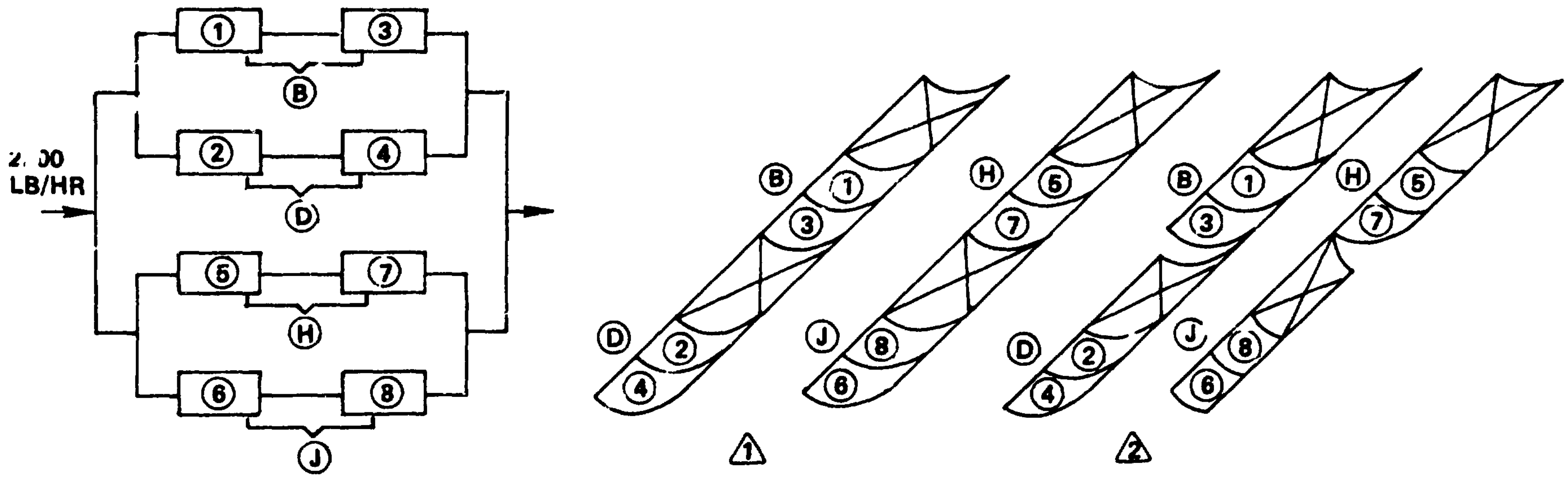


FIGURE 24
INSULATION DISPLACED FROM PANELS 6, 7, AND 8 DUE TO SECOND AND THIRD FREON 11 LINE RUPTURES

FIGURE 25

FLOW LOOP γ



EFFECTIVE AREAS

TEST

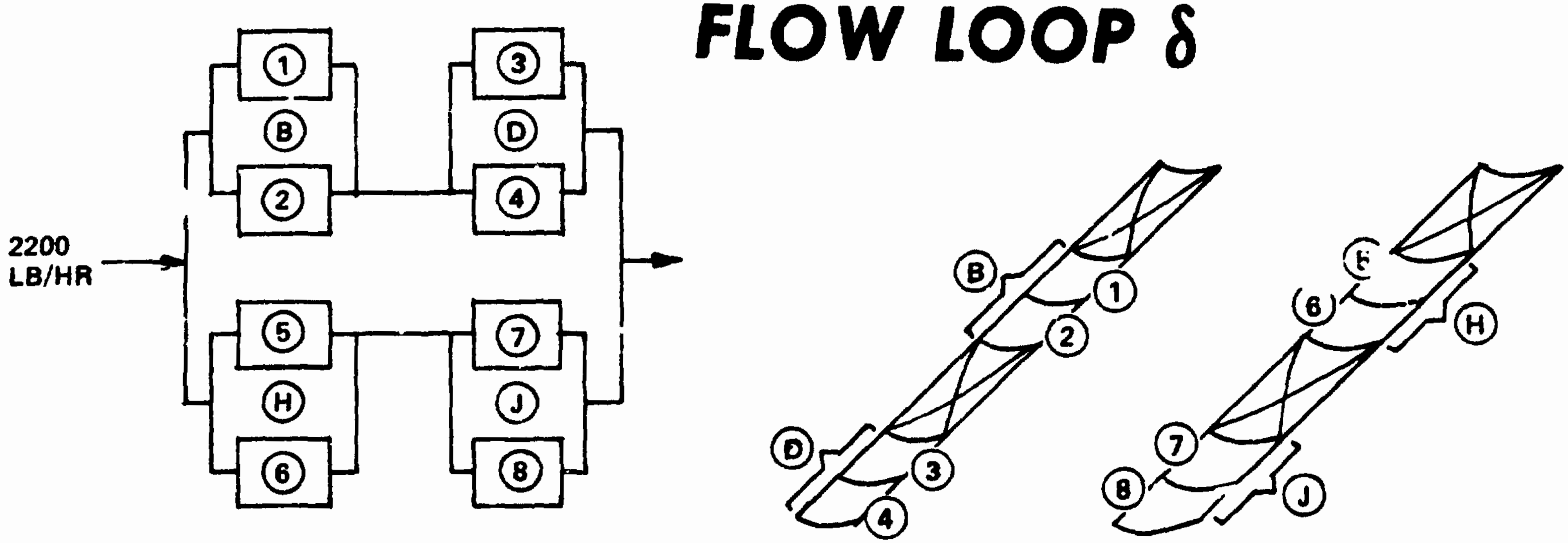
Σ ① → ⑧ = 8 X 72 = 576 FT^2

SIMULATES SHUTTLE

Σ B, D, H, J = 4 X 133 = 532 FT^2

FIGURE 26

FLOW LOOP δ



EFFECTIVE AREAS: TEST Σ 1 → 8 = 576 FT^2 SIMULATED SHUTTLE Σ B, D, H, J = 532 FT^2

FIGURE 27

FLOW LOOP ϵ

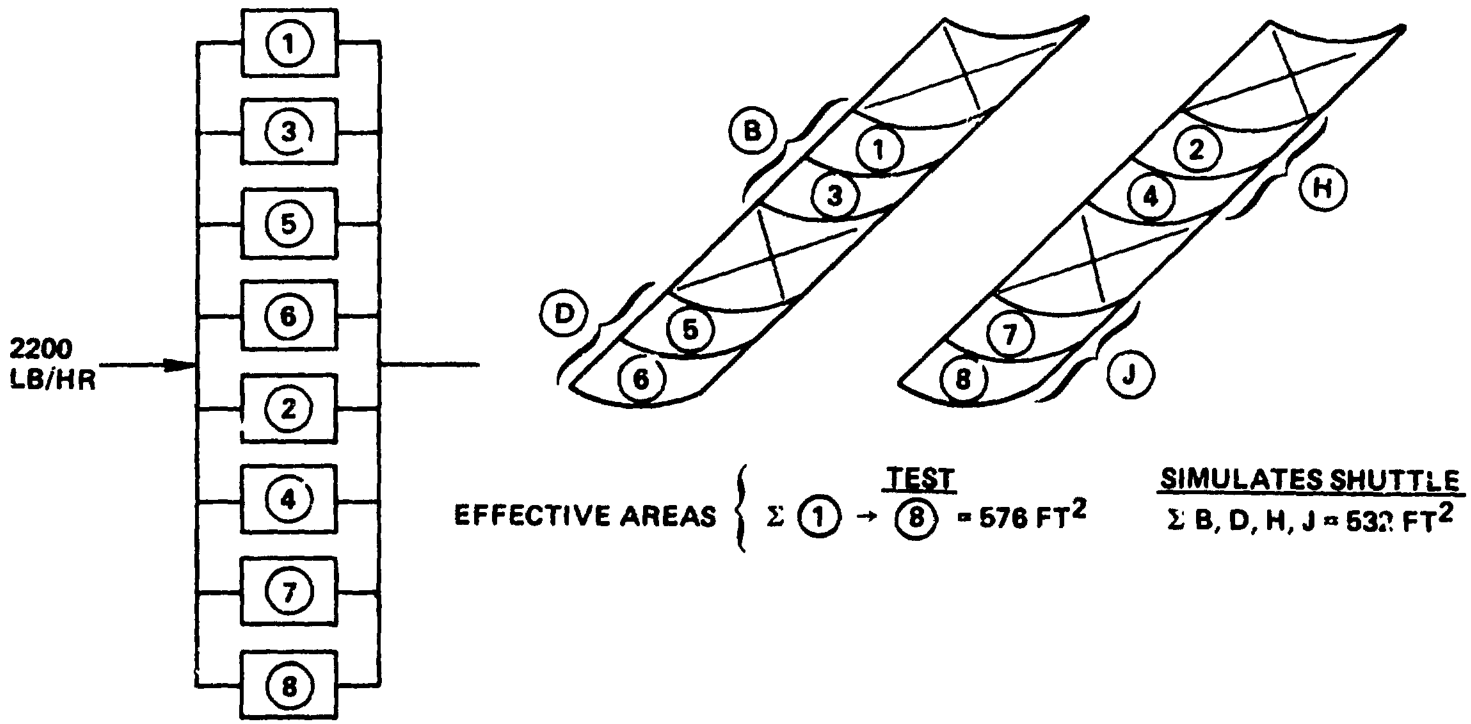


FIGURE 28

SUMMARY OF WEEK 2 FLOW CONFIGURATIONS

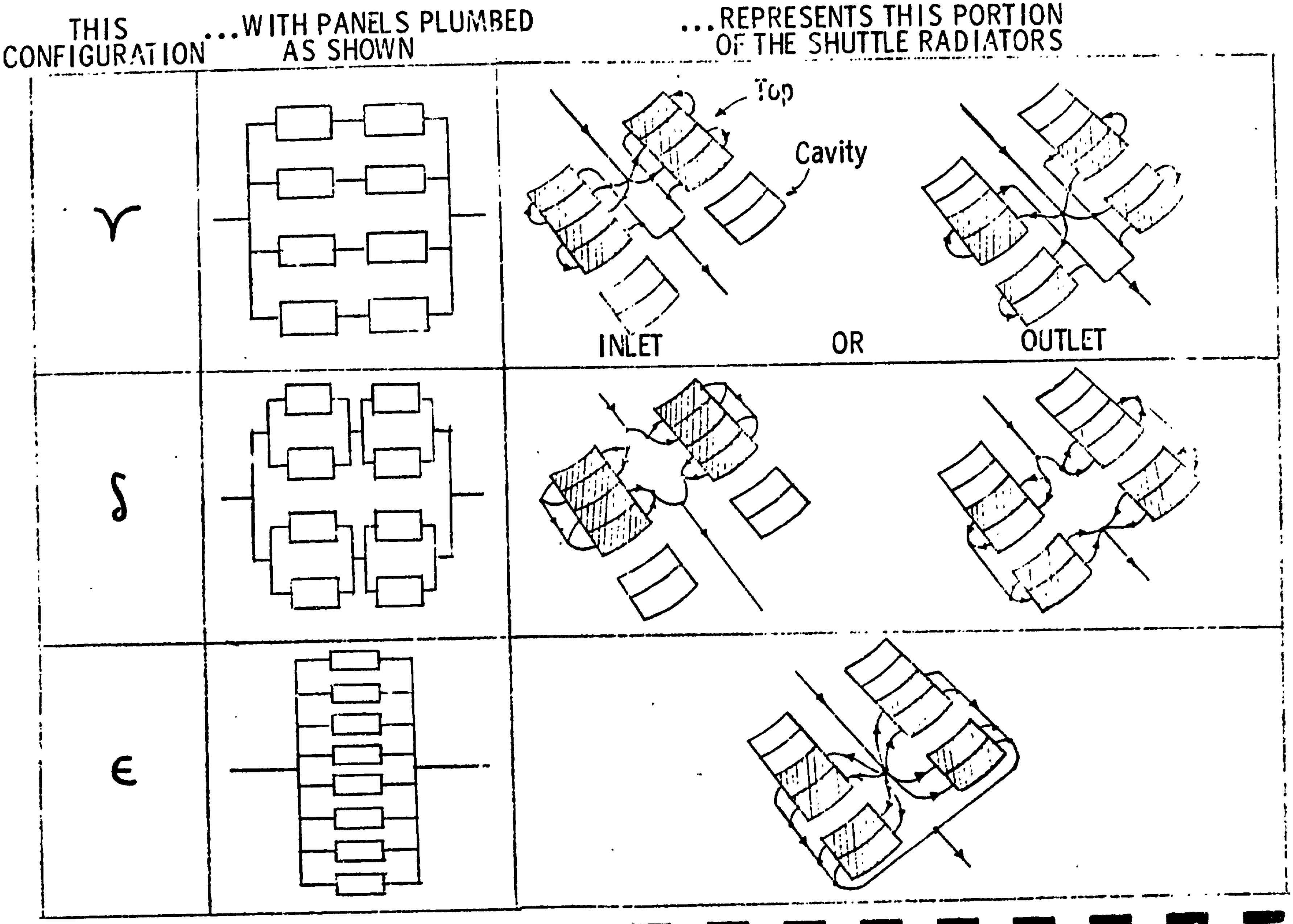


FIGURE 29

FLOW LOOP SIMULATING TWO-SIDED RADIATION FROM THE FORWARD 30' OF THE CARGO BAY DOORS

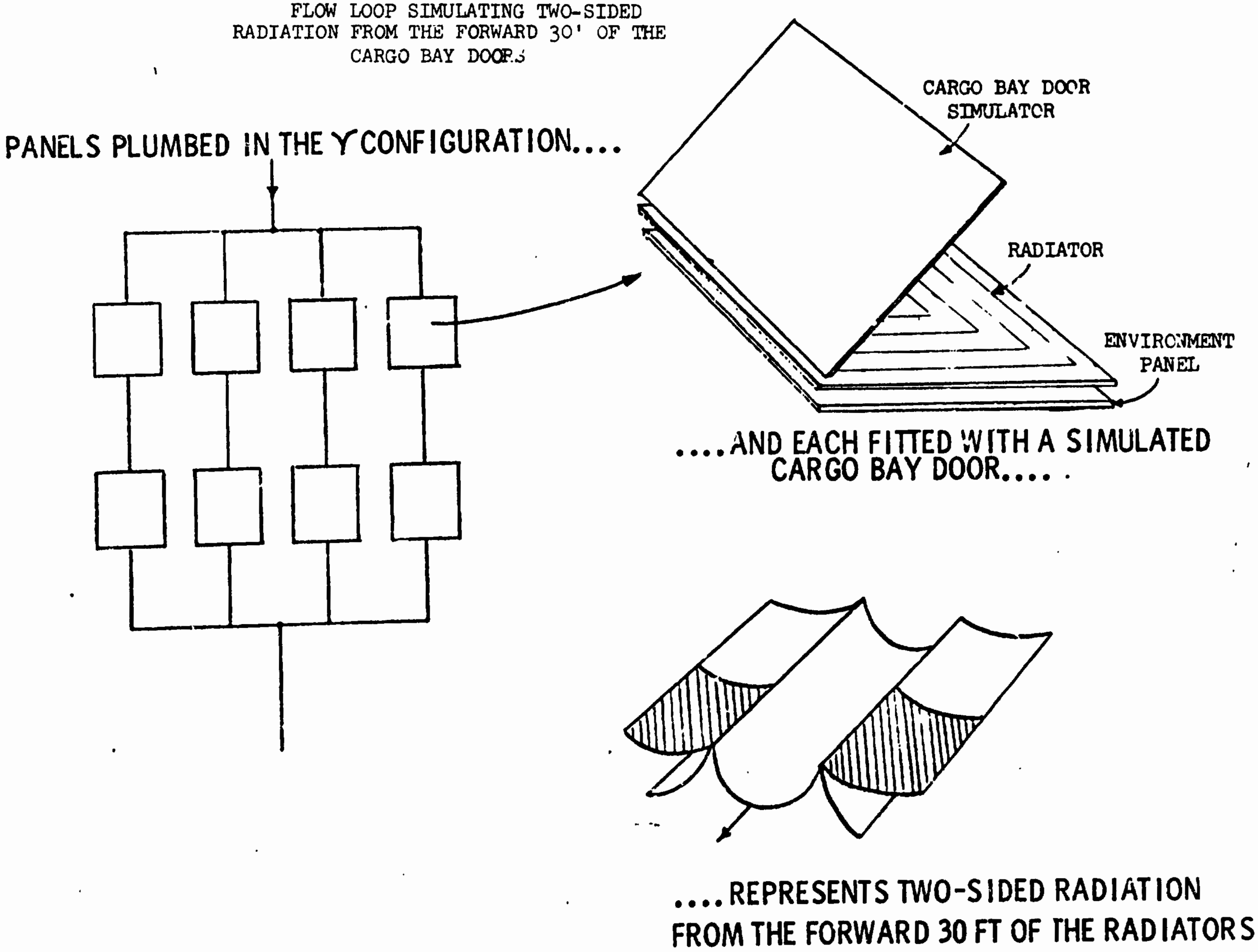


FIGURE 30

TEST POINT 1[illegible] - STABILIZED TEMPERATURES

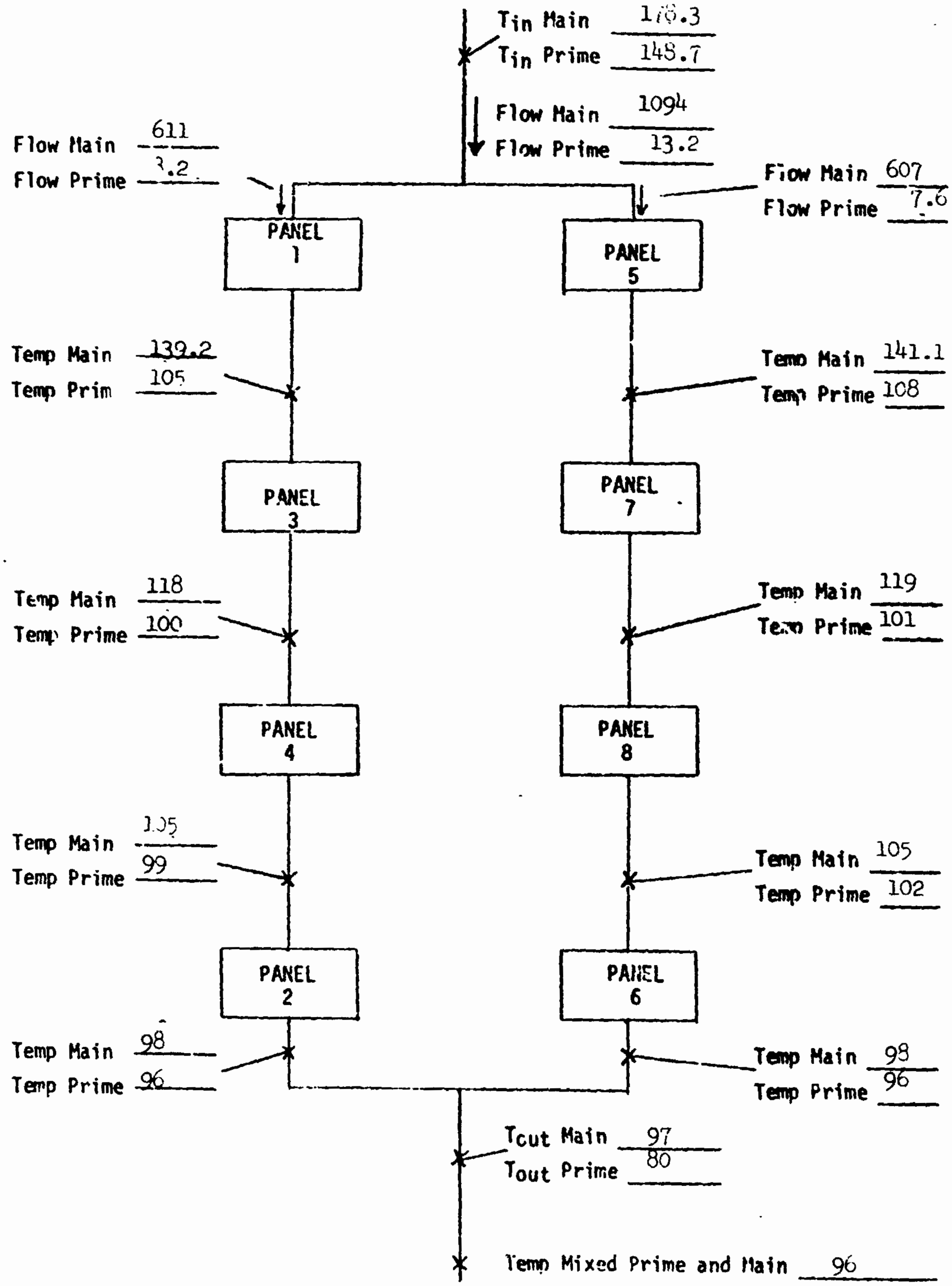


FIGURE 31
TEST POINT 5A - MIXED AND MAIN OUTLET
TEMPERATURES

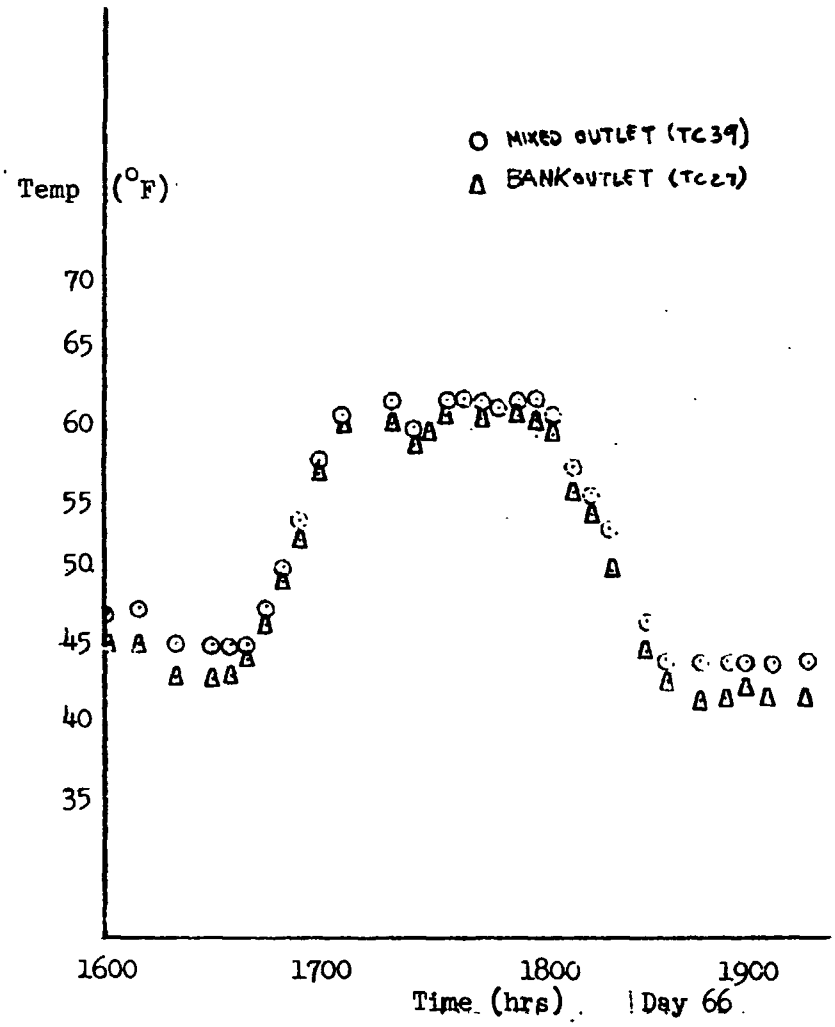


FIGURE 32

TEST POINT 5A - LEG FLOW RATES AND
OUTLET TEMPERATURES

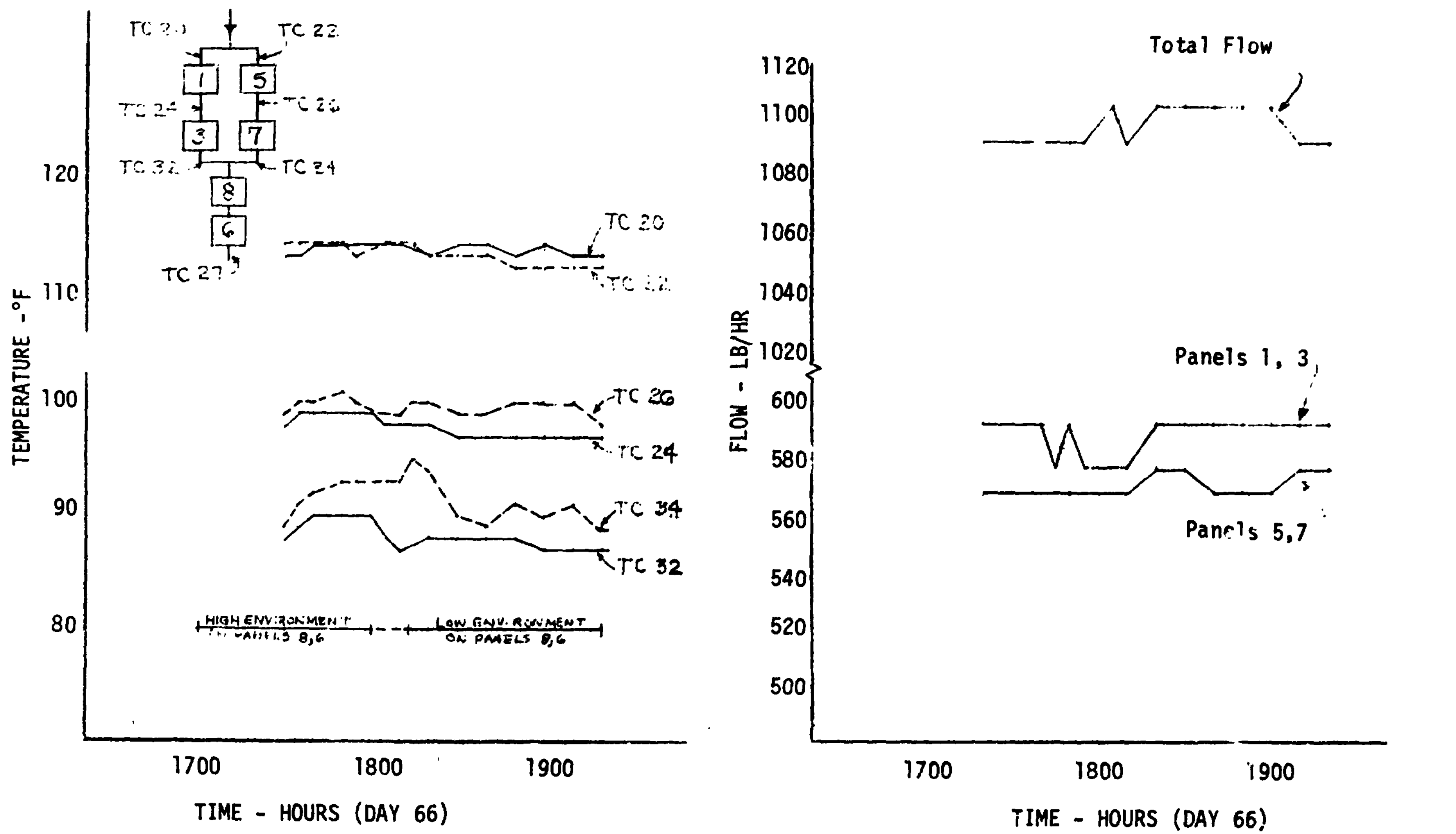


FIGURE 33

TEST POINT 1 - STABILIZED TEMPERATURES

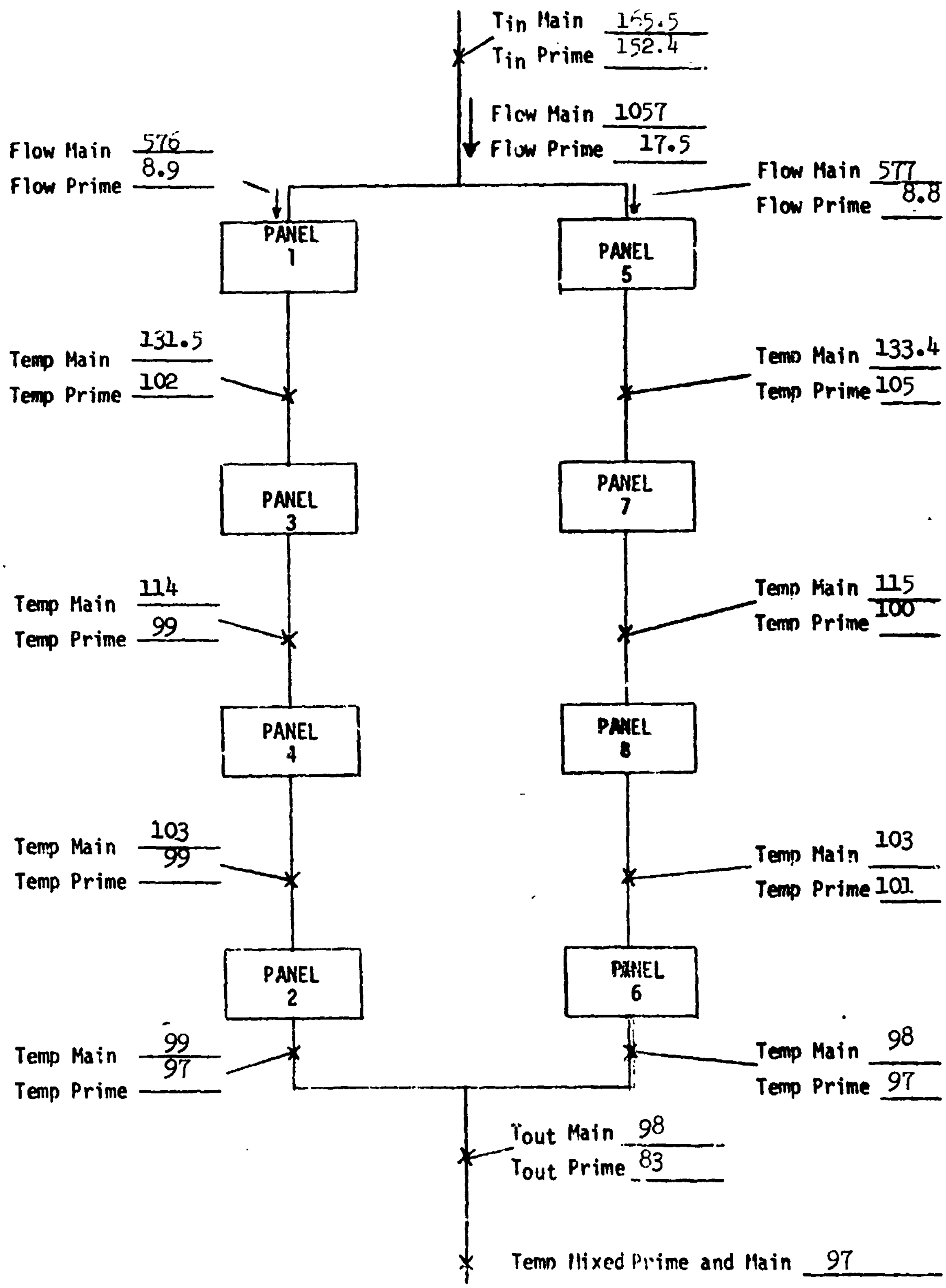


FIGURE 34

TEST POINT 3 - STABILIZED TEMPERATURES

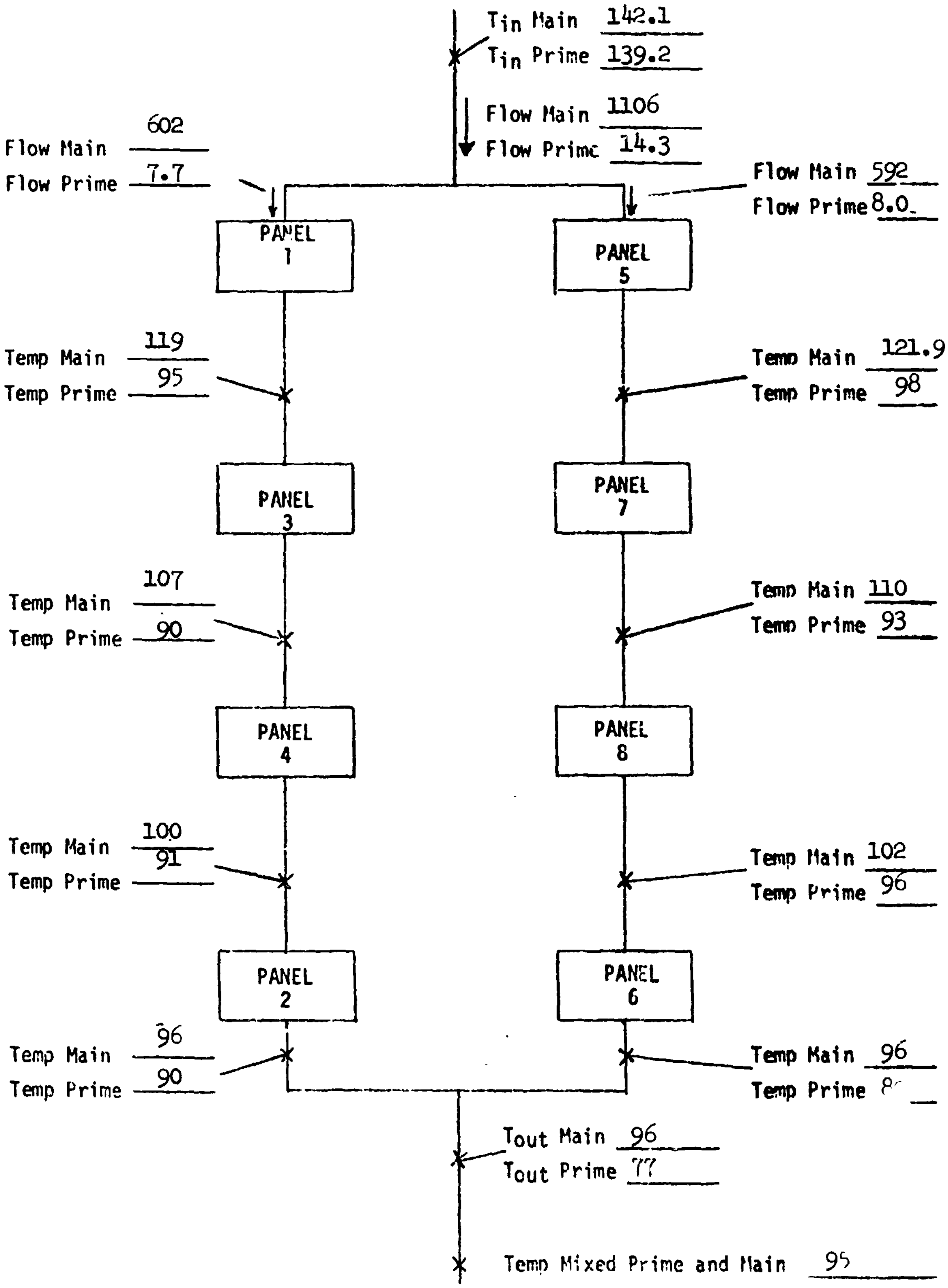


FIGURE 35

TEST POINT 20 - MIXED OUTLET AND LEG
OUTLET TEMPERATURES

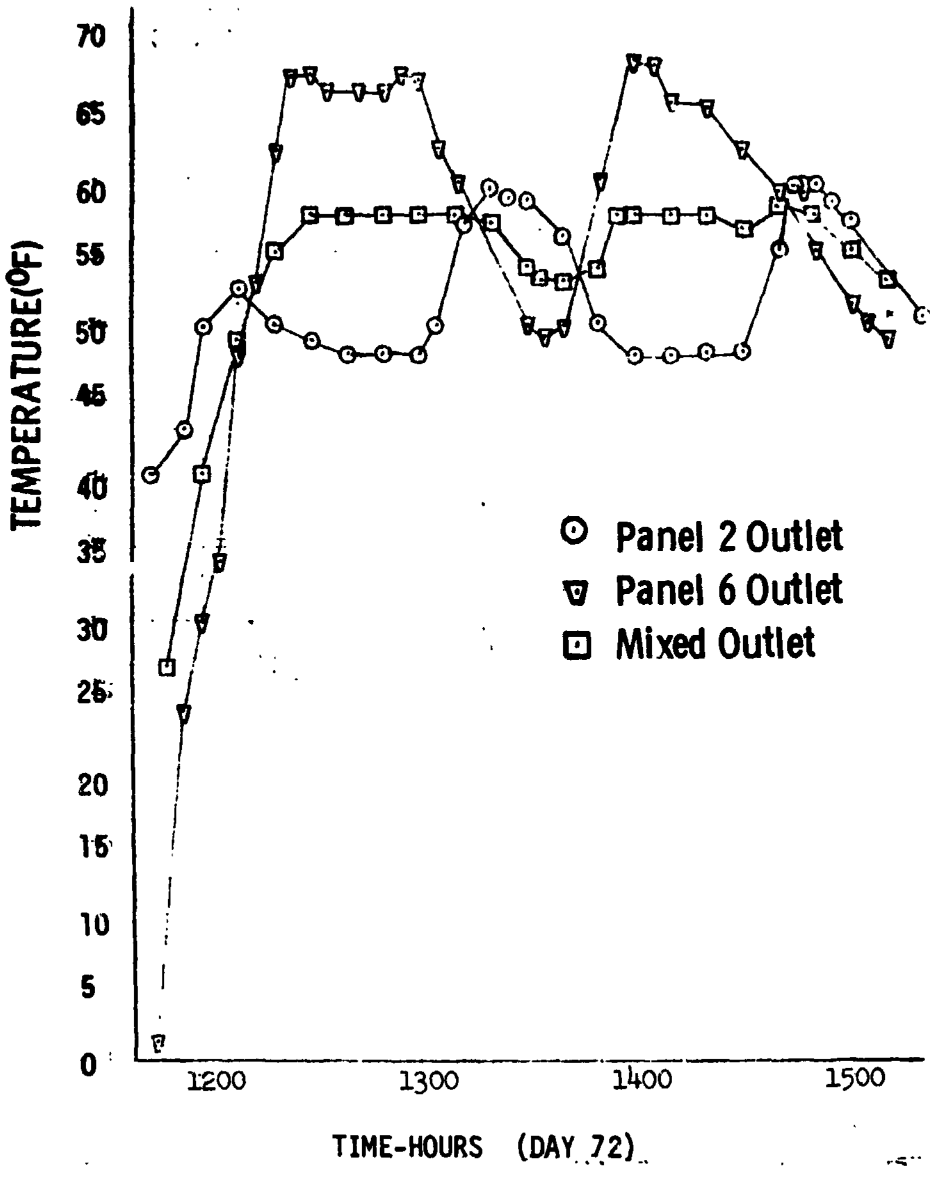


FIGURE 36

TEST POINT 20 - LEG FLOW RATES

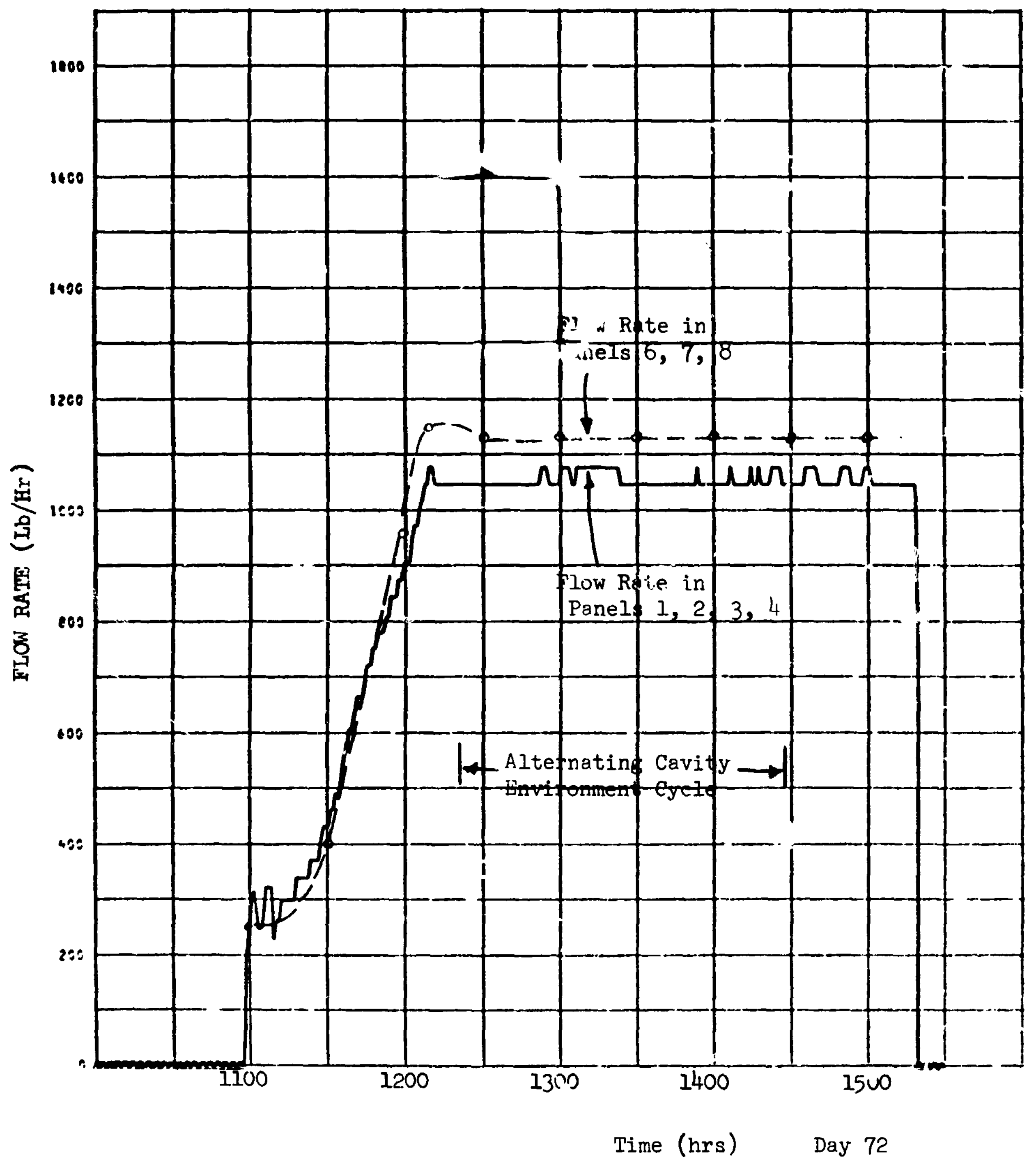


FIGURE 37

TEST POINT 4 - STABILIZED TEMPERATURES

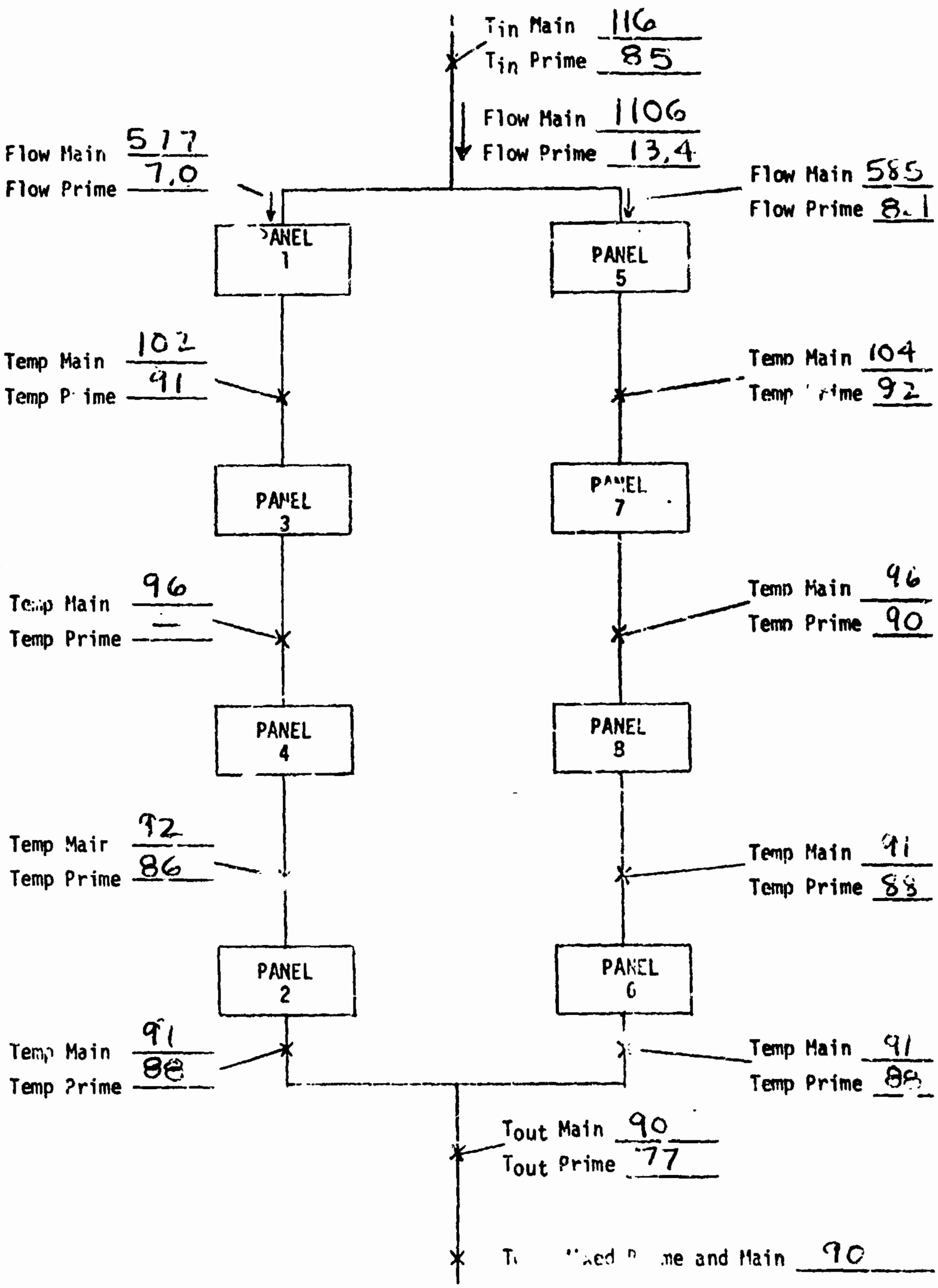
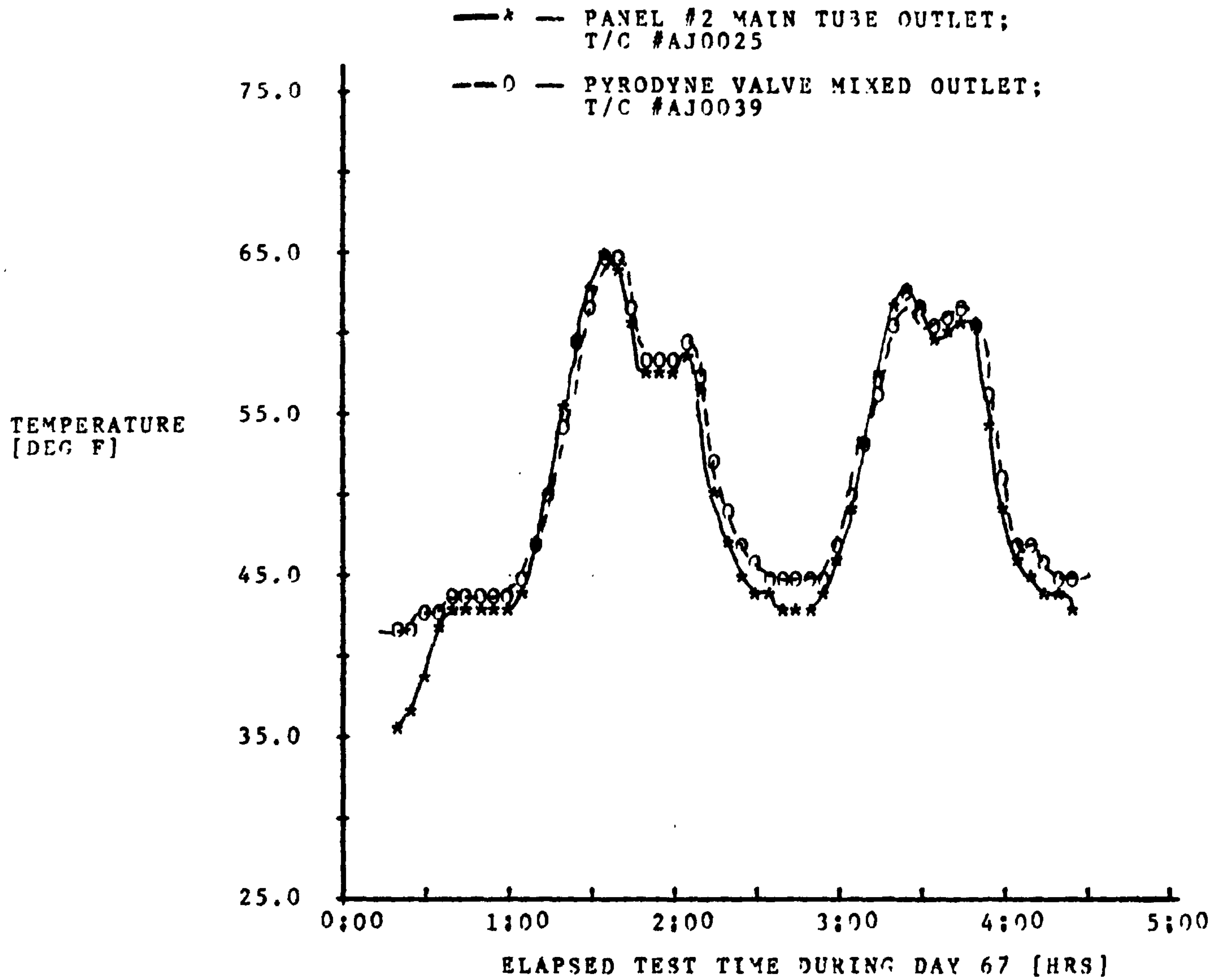


FIGURE 38

TEST POINT 8 - MIXED AND MAIN OUTLET TEMPERATURES



C-2

FIGURE 39

TEST POINT 8 - INLET TEMP AND LEG OUTLET TEMPERATURES

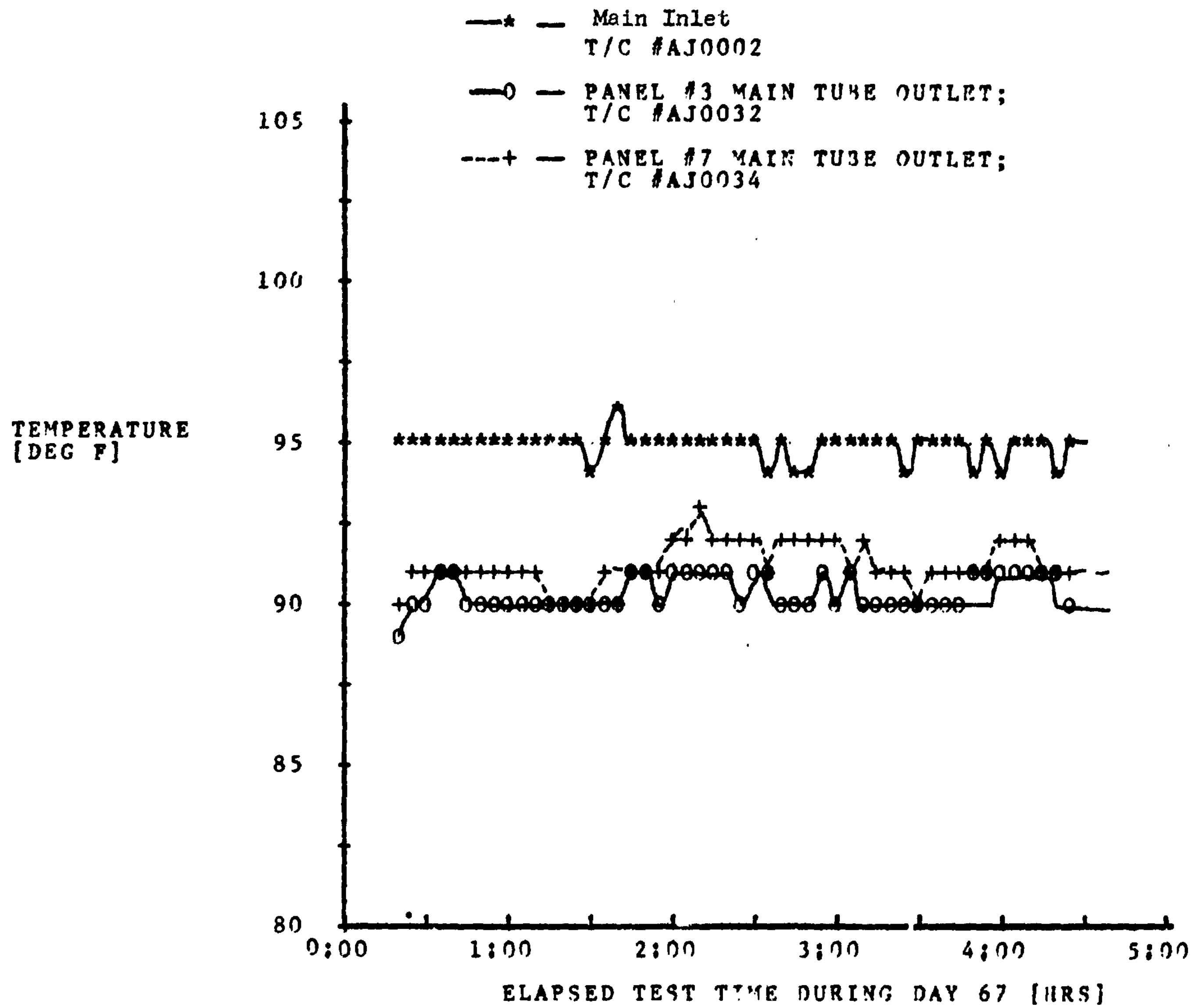


FIGURE 40

TEST POINT 8 - LEG AND TOTAL FLOW RATES

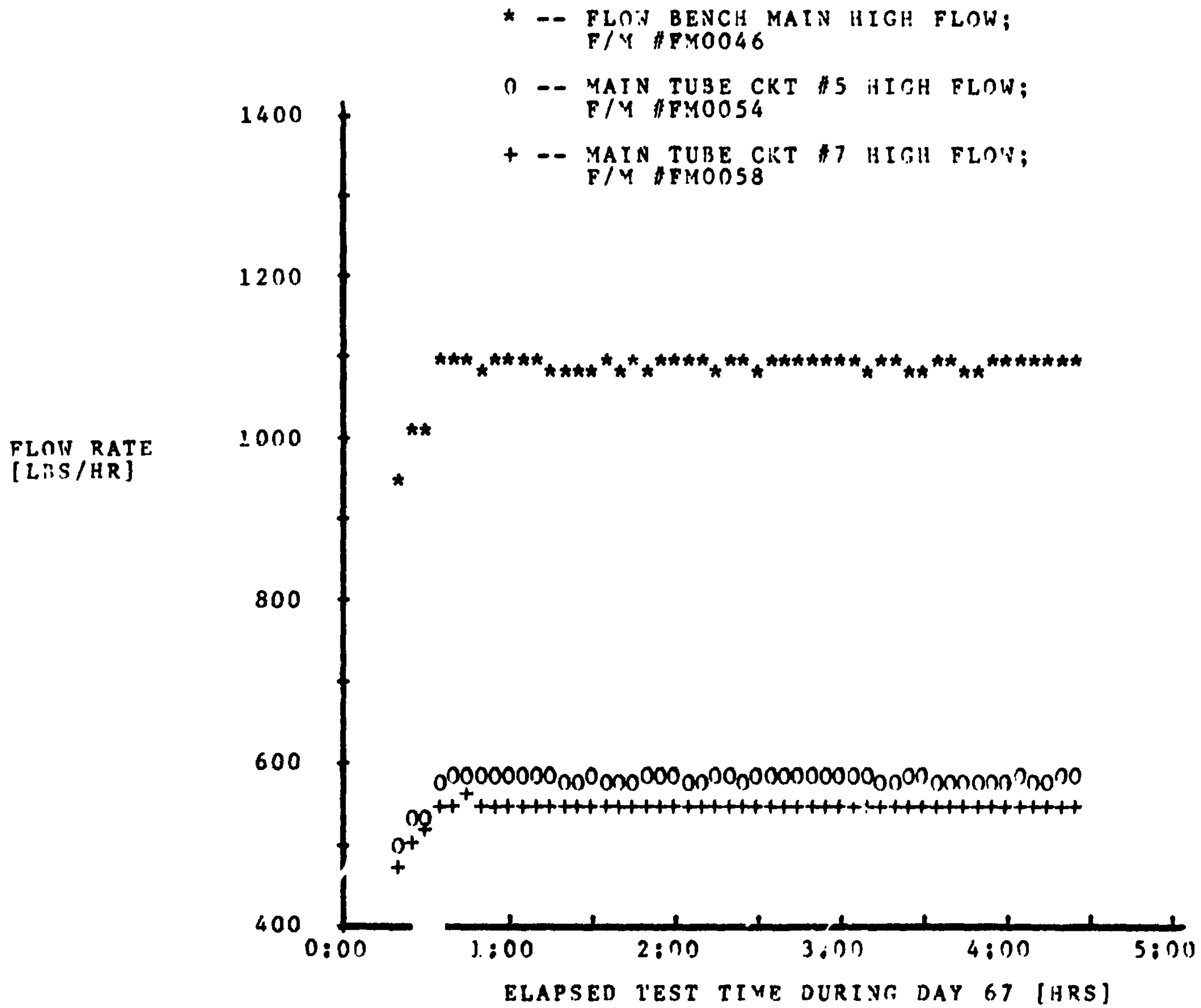


FIGURE 41

TEST POINT 10 - STABILIZED TEMPERATURES

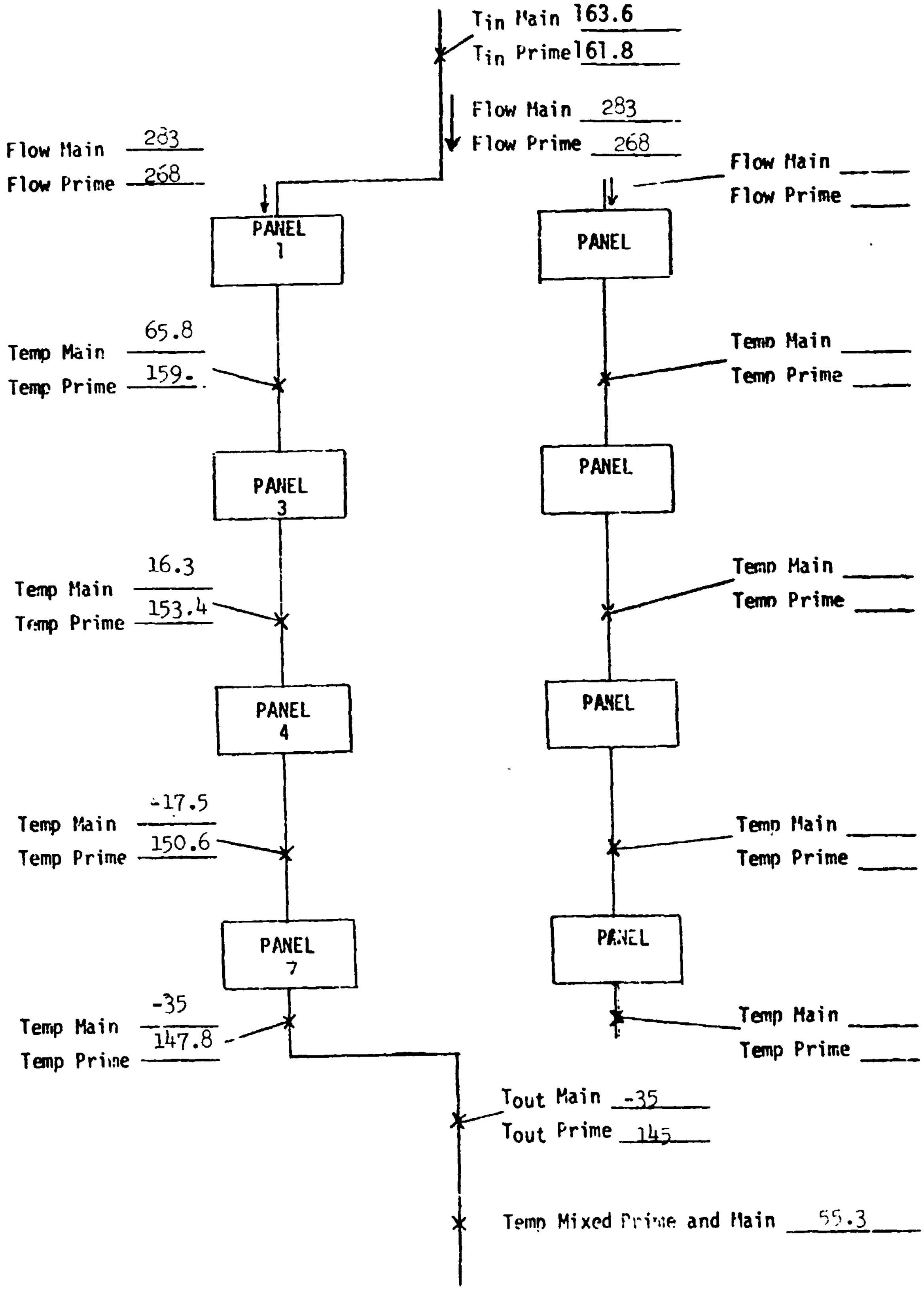


FIGURE 42

TEST POINT 11 - STABILIZED TEMPERATURES

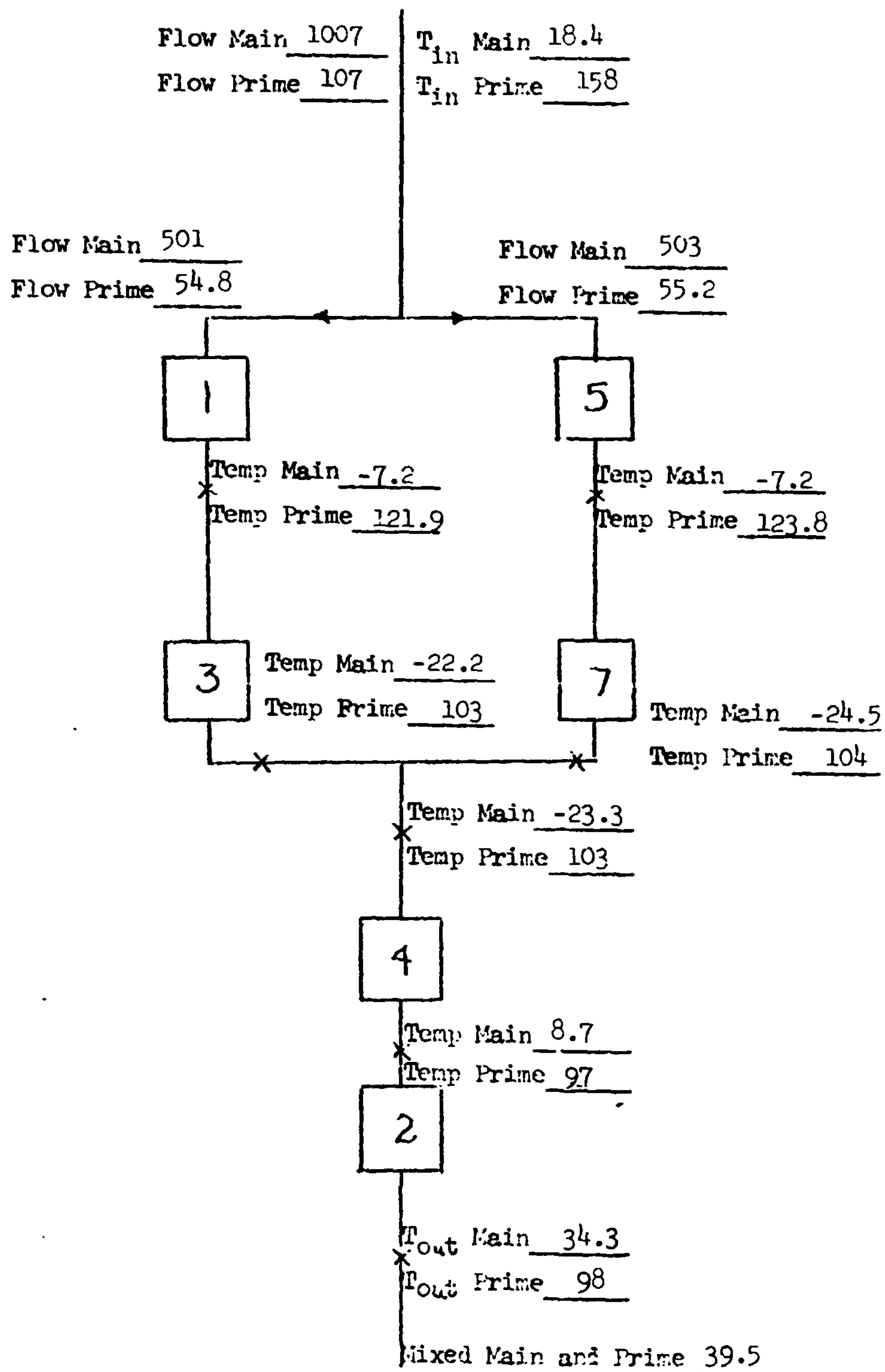


FIGURE 43

TEST POINT 12 - STABILIZED TEMPERATURES

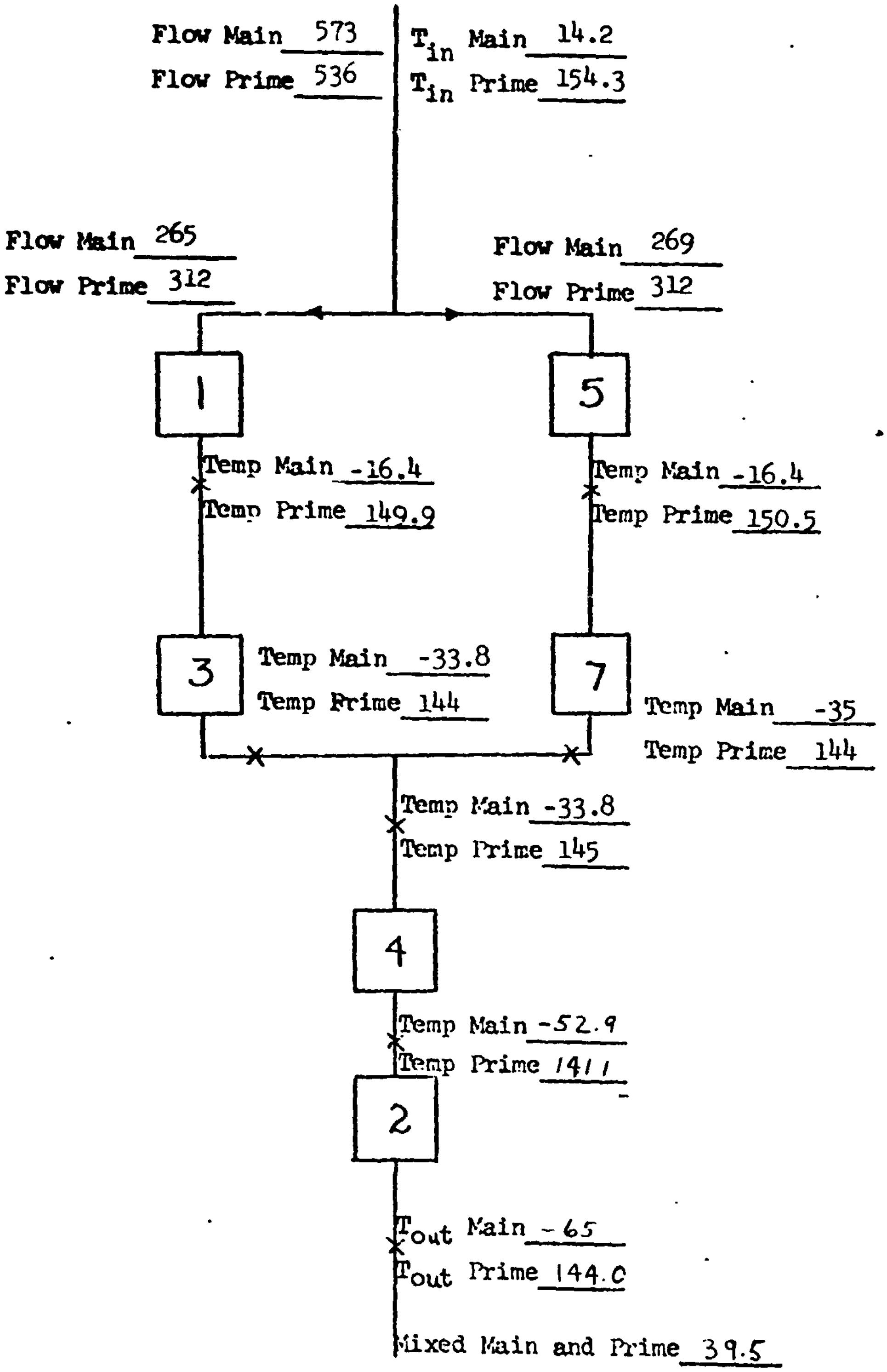


FIGURE 44

TEST POINT 14 - STABILIZED TEMPERATURES

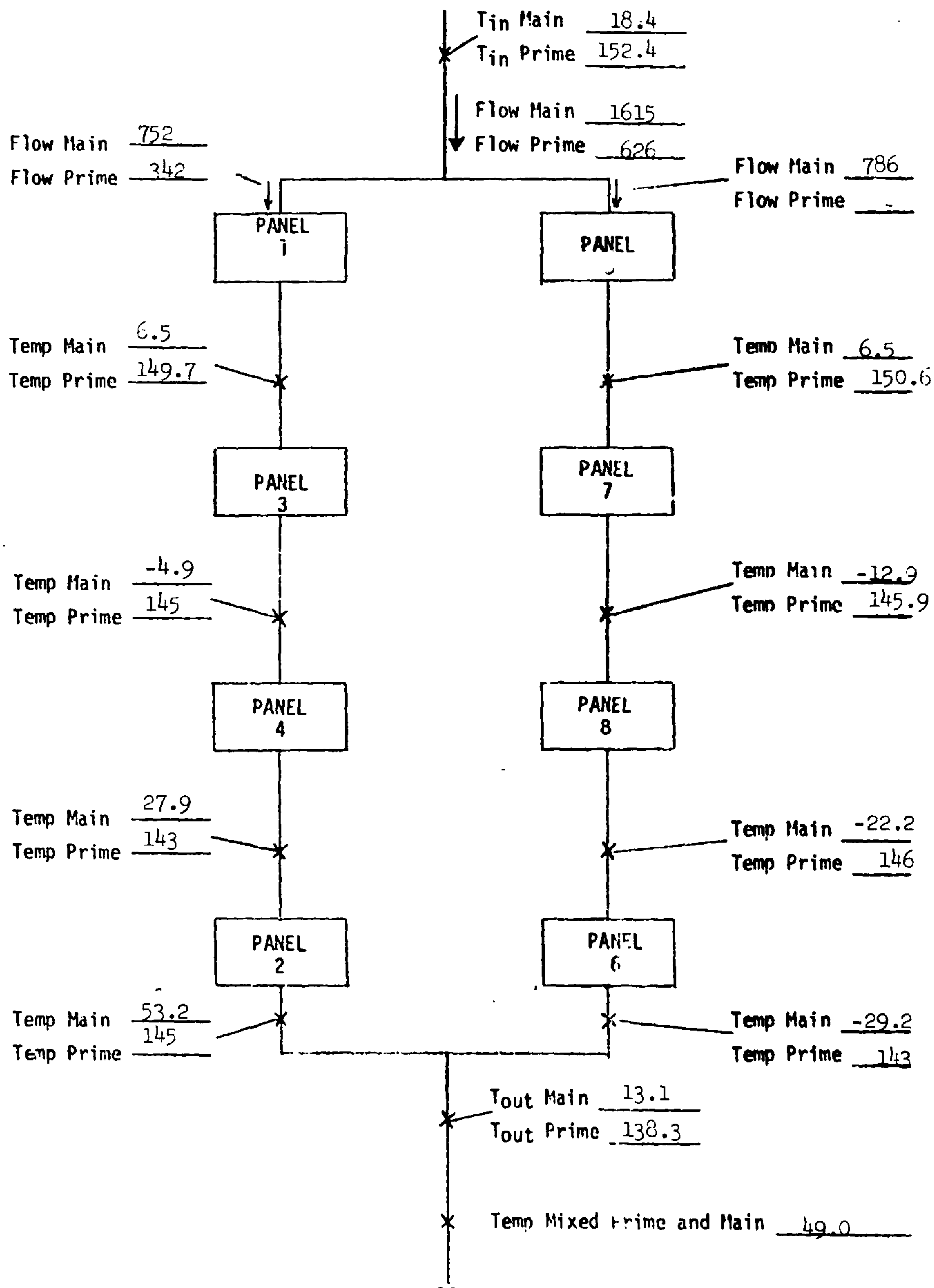


FIGURE 45

TEST POINT 14, 14A - INLET TEMPERATURE, PRIME, BANK AND MIXED OUTLET TEMPERATURES

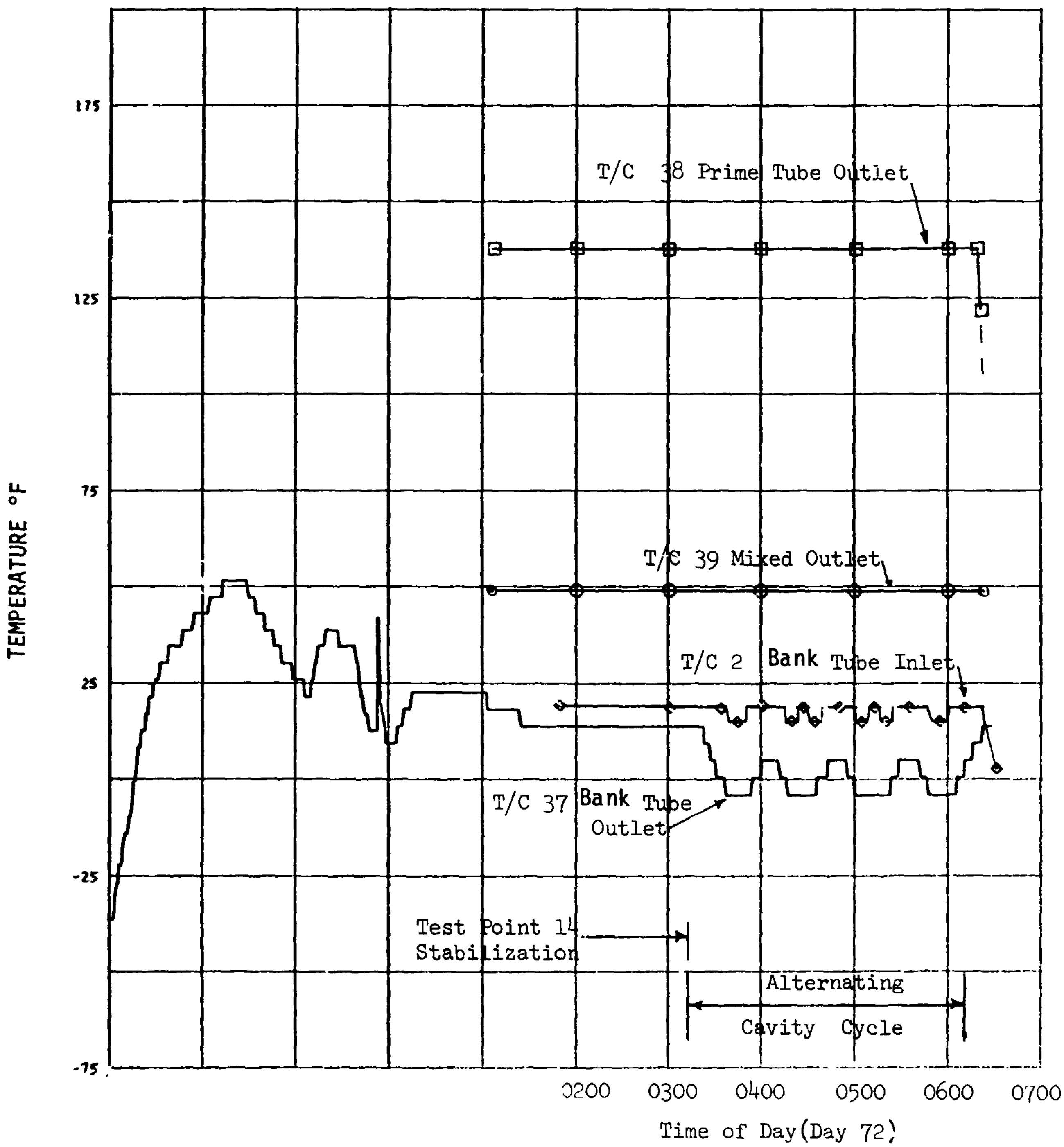


FIGURE 46

TEST POINT 14, 14A - BANK TUBE OUTLET TEMPERATURES, PANELS 2 AND 6

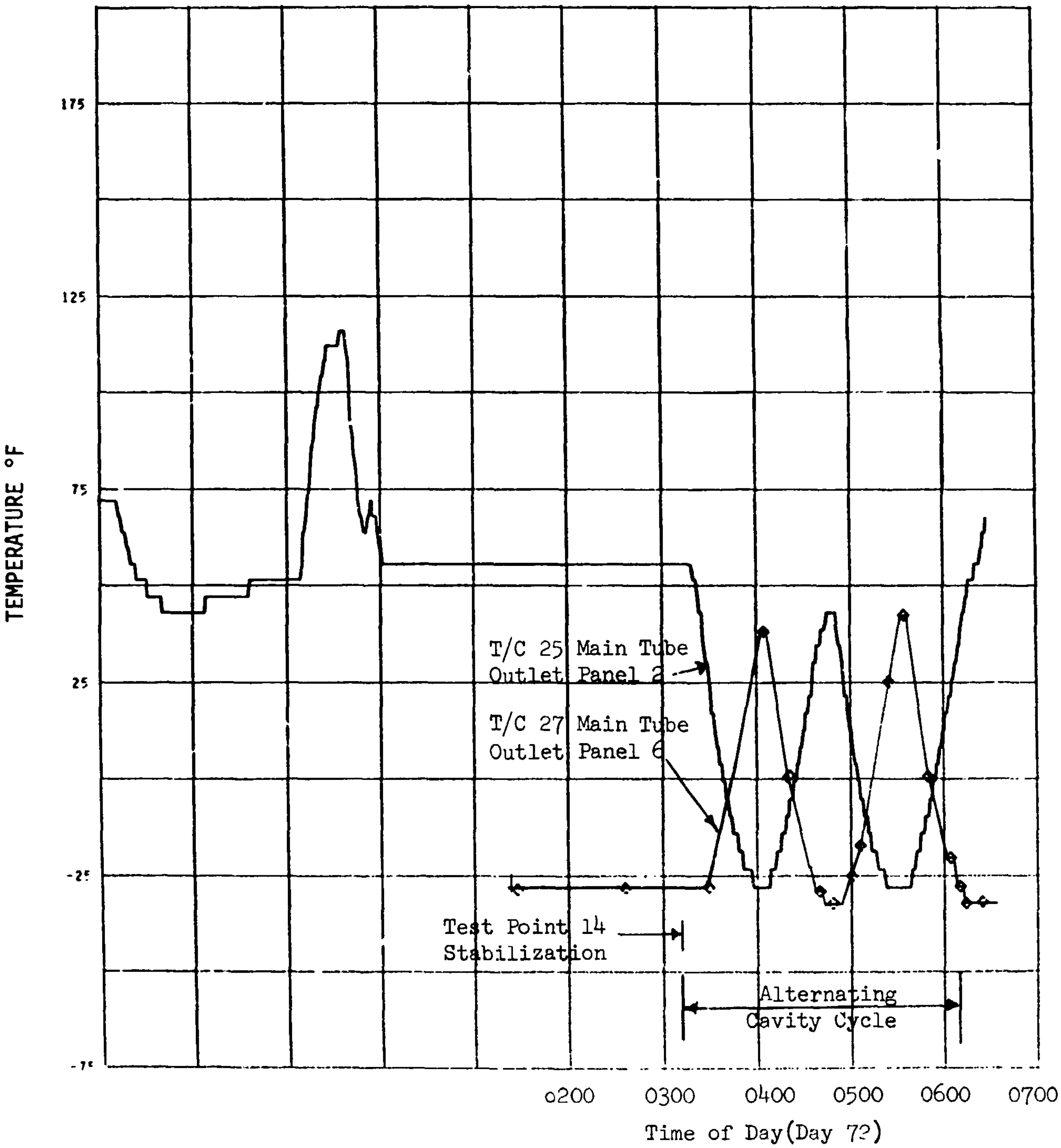


FIGURE 47

TEST POINT 14, 14A - TOTAL, BANK, PRIME FLOW RATES

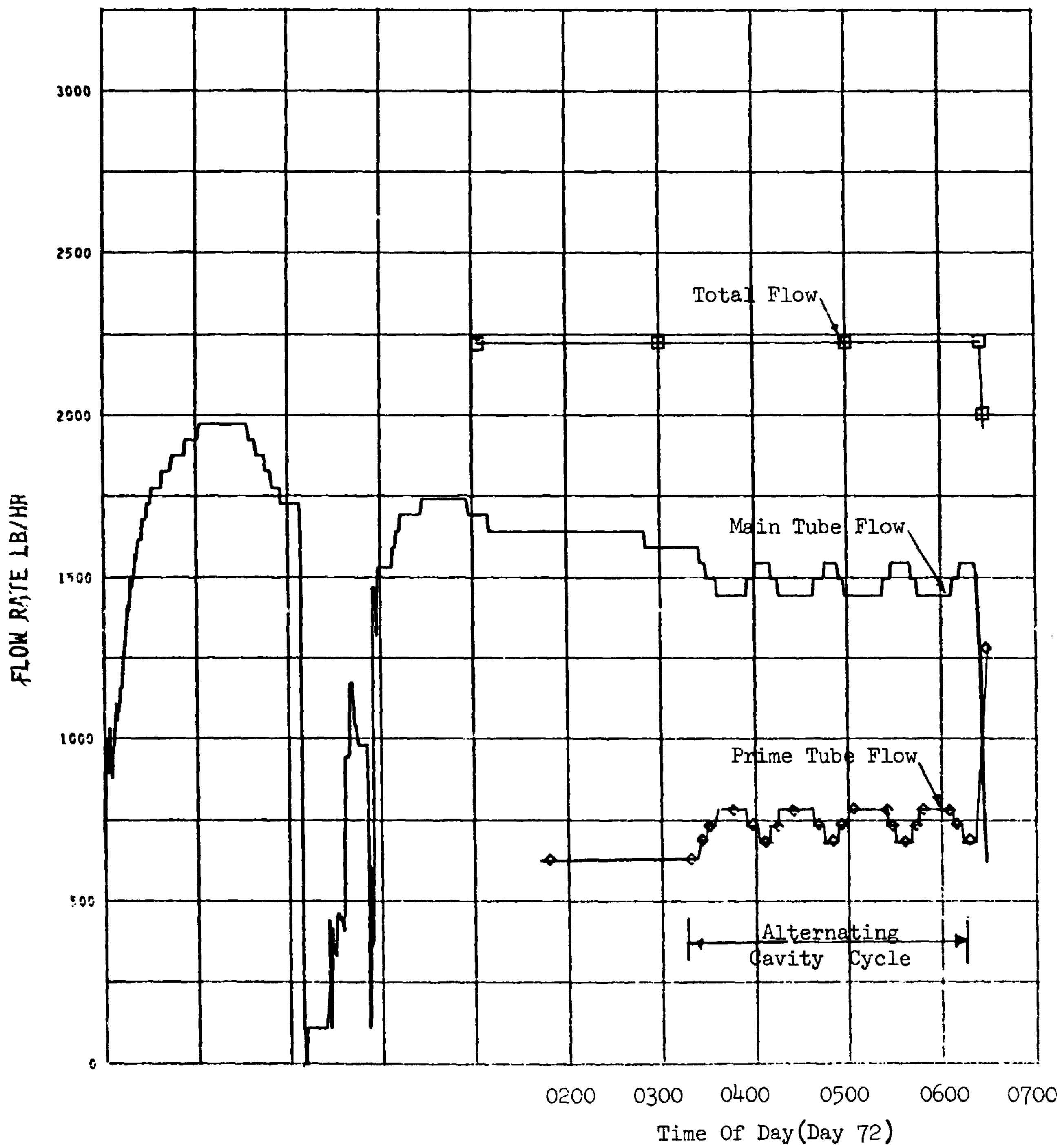


FIGURE 48

TEST POINT 14, 14A - LEG FLOW RATES

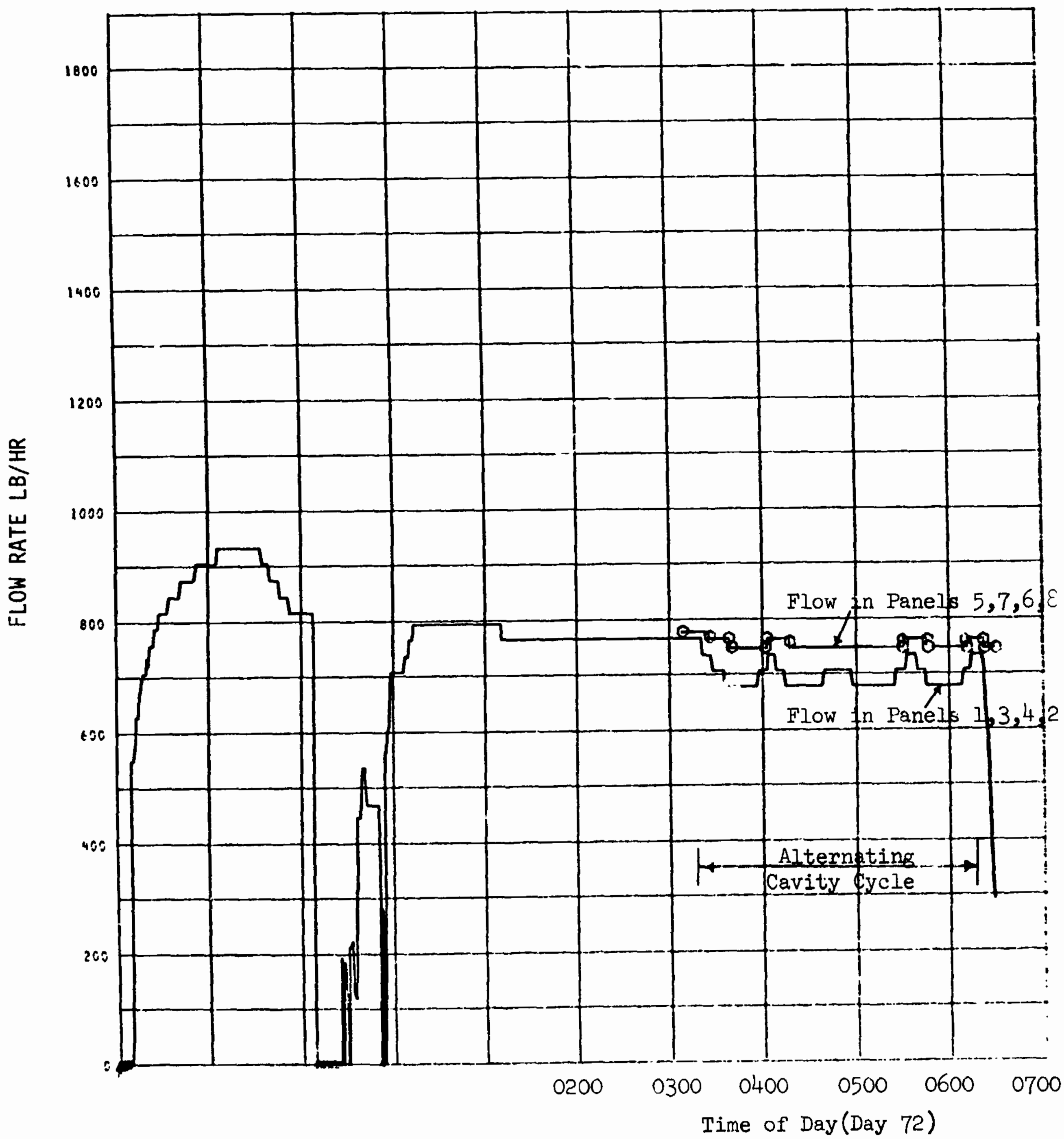


FIGURE 49

TEST POINT 17 - STABILIZED TEMPERATURES

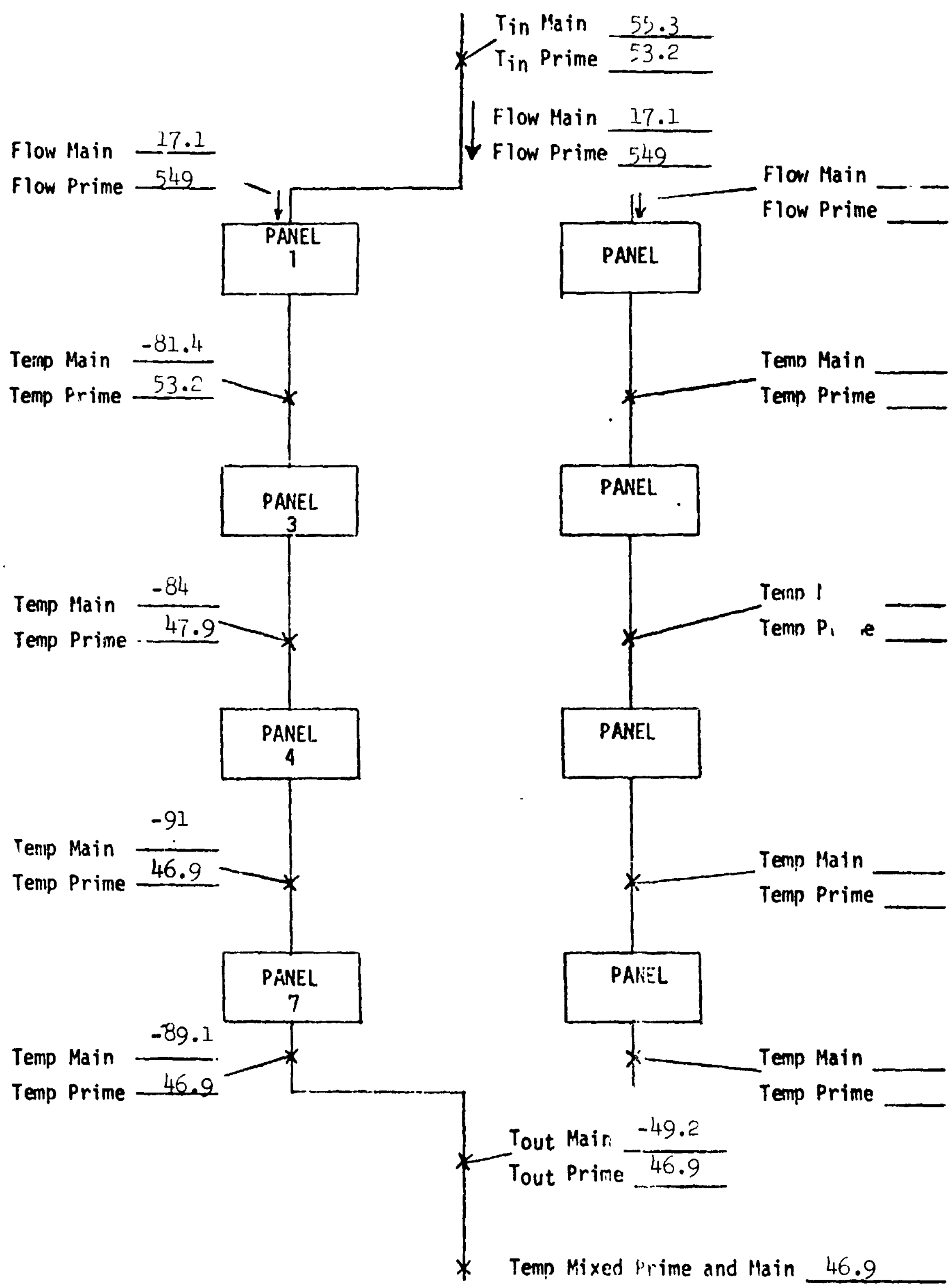


FIGURE 50

TEST POINT 17A - STABILIZED TEMPERATURES

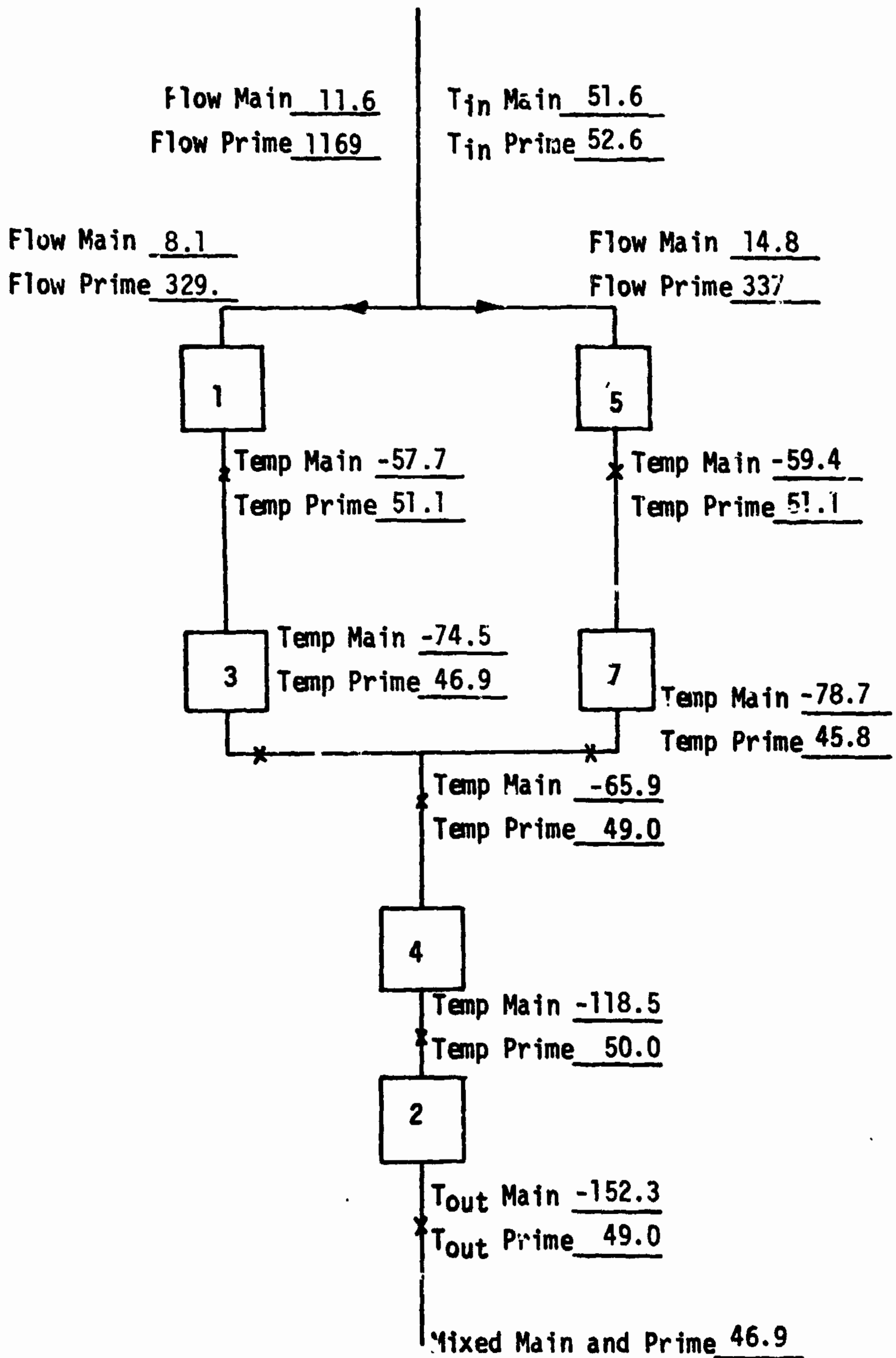


FIGURE 51

TEST POINT 16-1 - STABILIZED TEMPERATURES

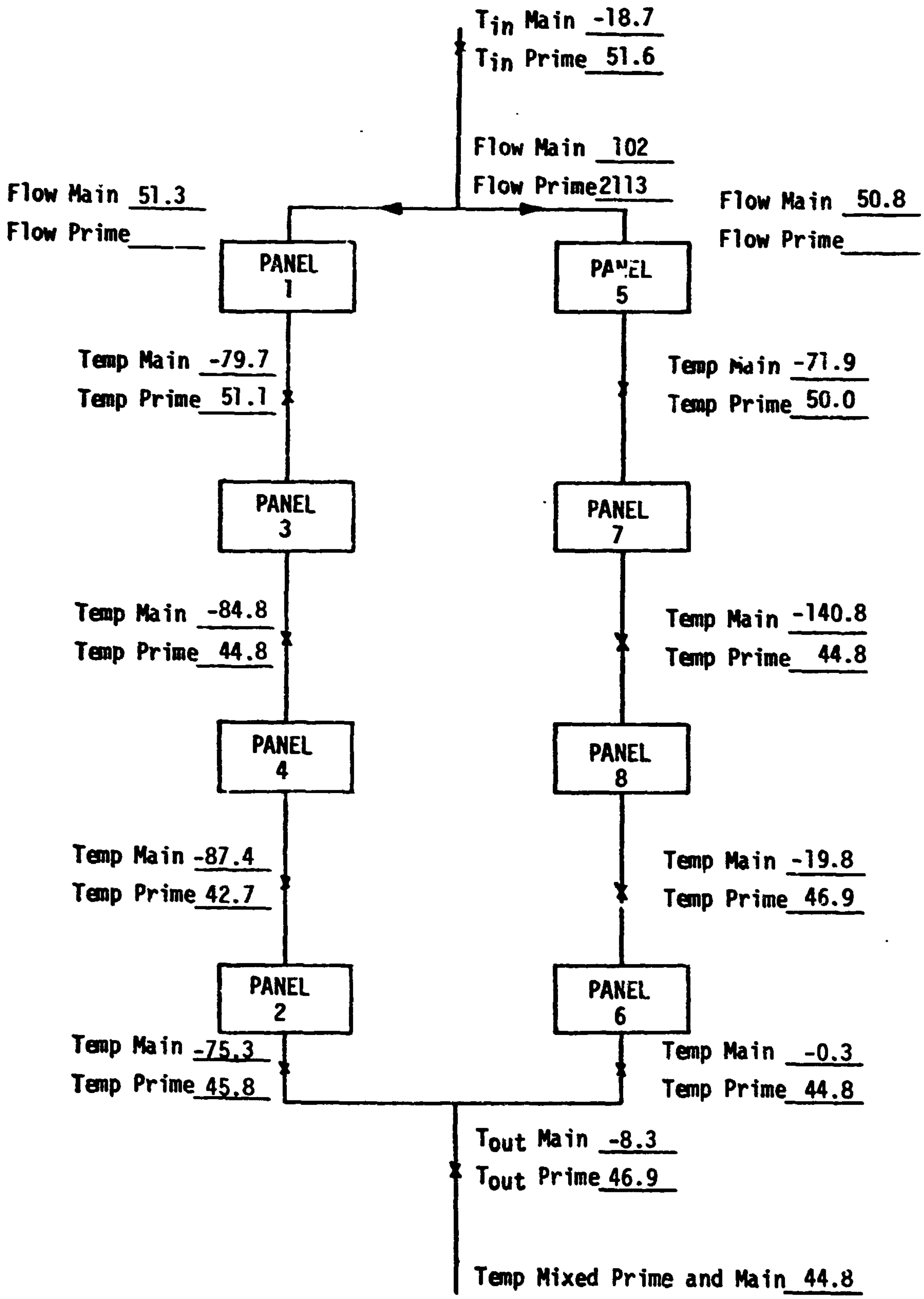


FIGURE 52

TEST POINT 16-2 - STABILIZED TEMPERATURES

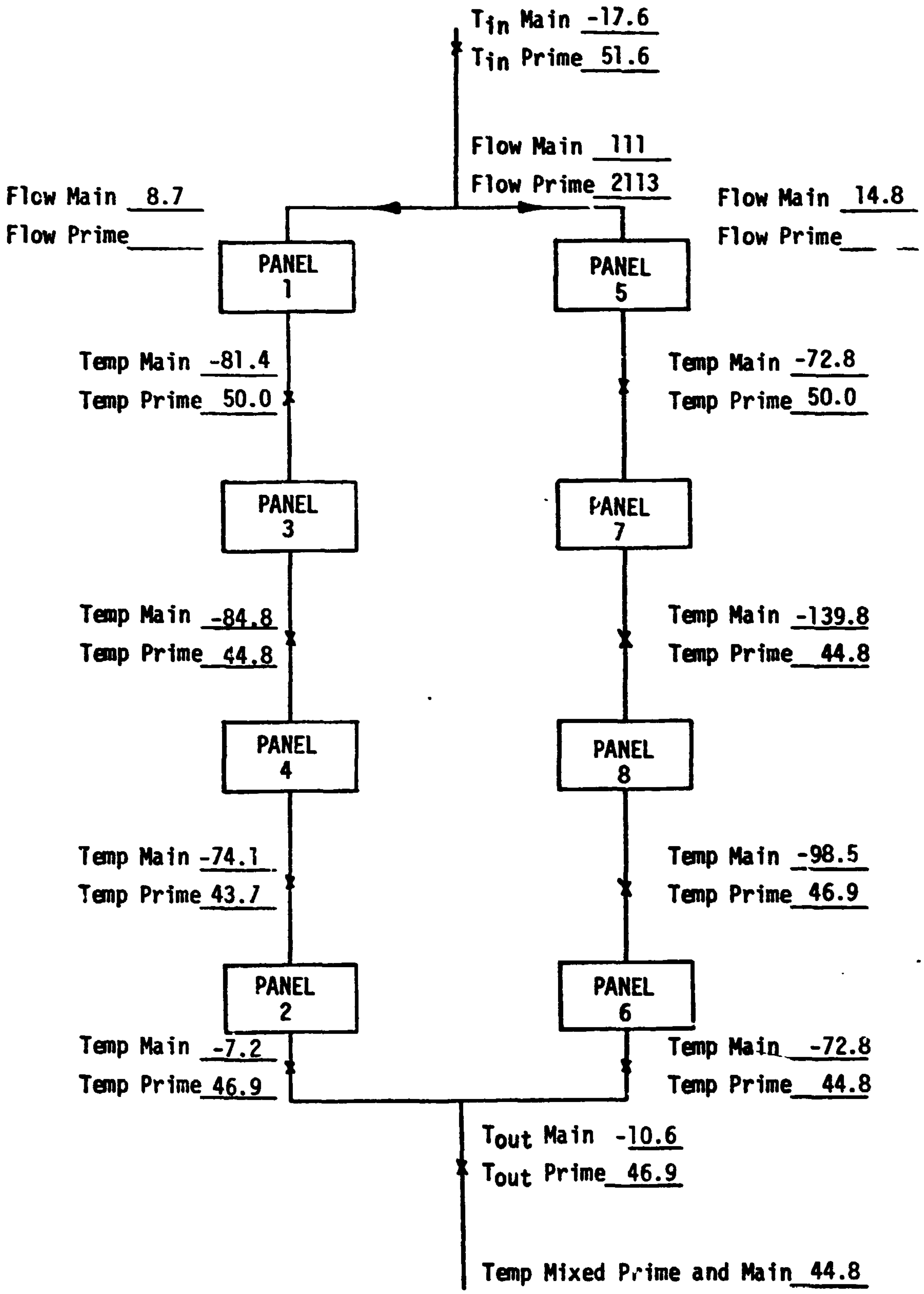


FIGURE 53

TEST POINT 16 - PANEL 2 AND 6 OUTLET TEMPERATURES, MIXED OUTLET TEMPERATURES, MIXED OUTLET TEMPERATURE

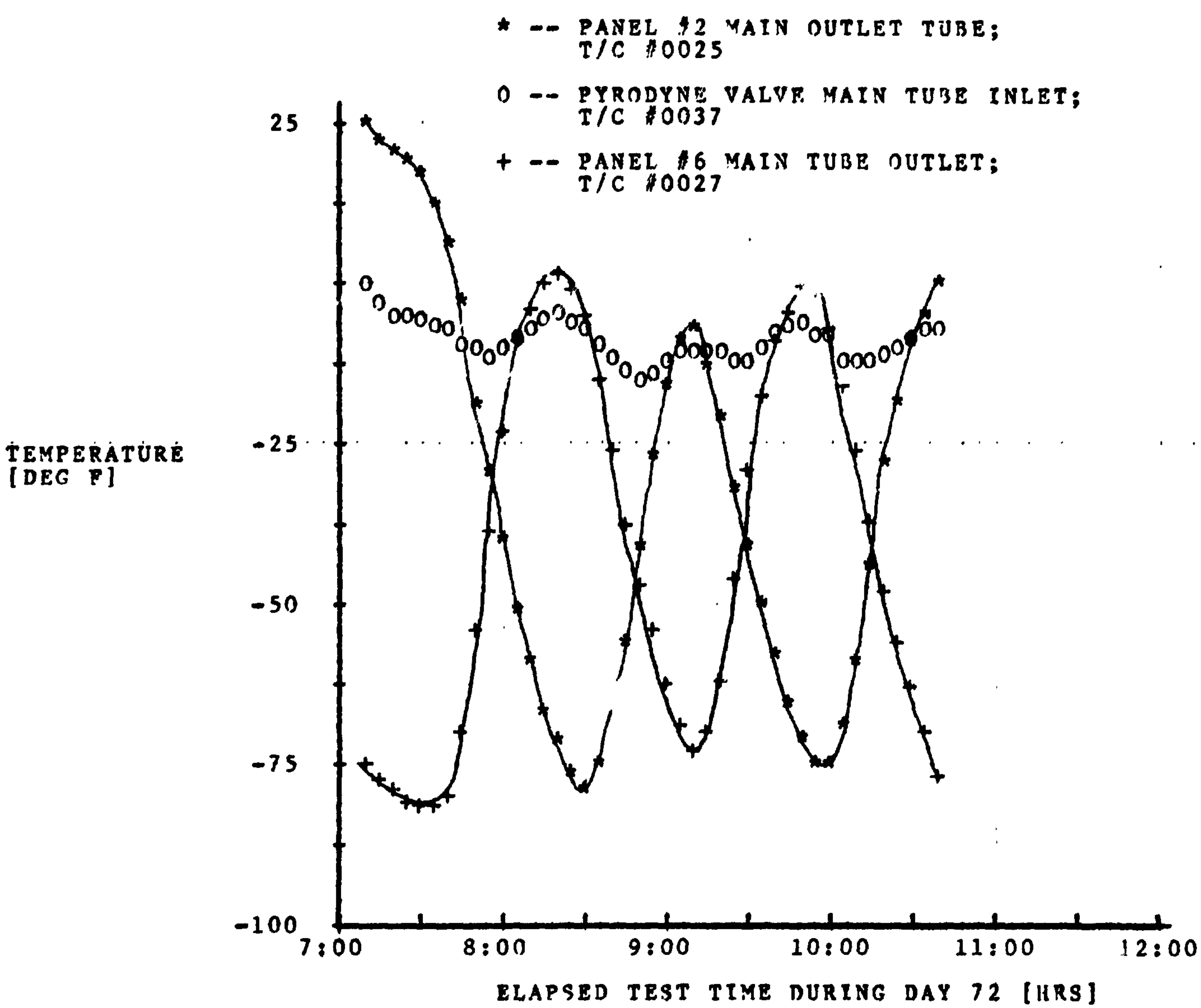


FIGURE 54

TEST POINT 18 - STABILIZED TEMPERATURES

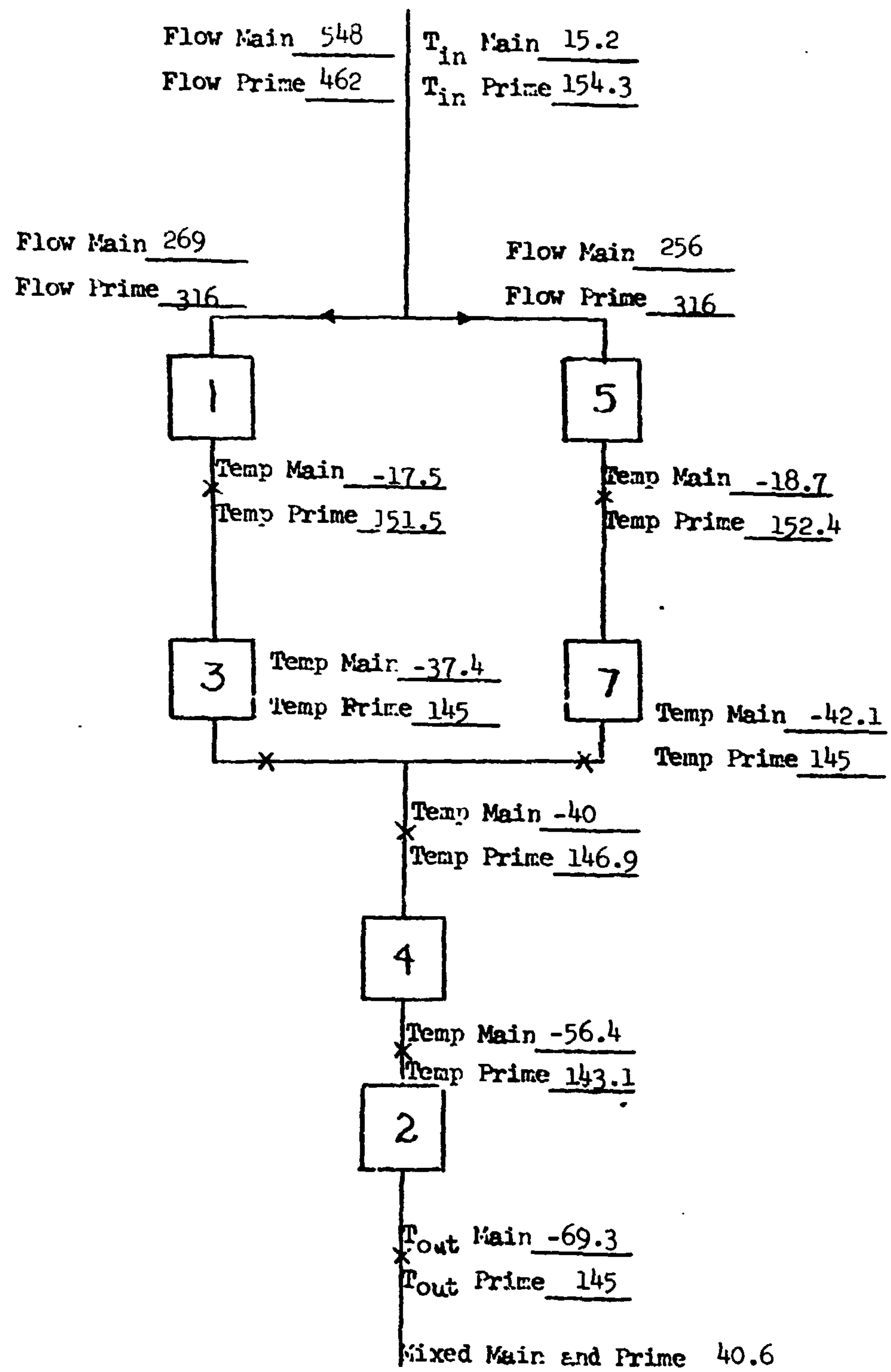


FIGURE 55

INFLUENCE OF ENVIRONMENT ON PERFORMANCE

COMPARISON OF TEST POINTS 5 AND 8

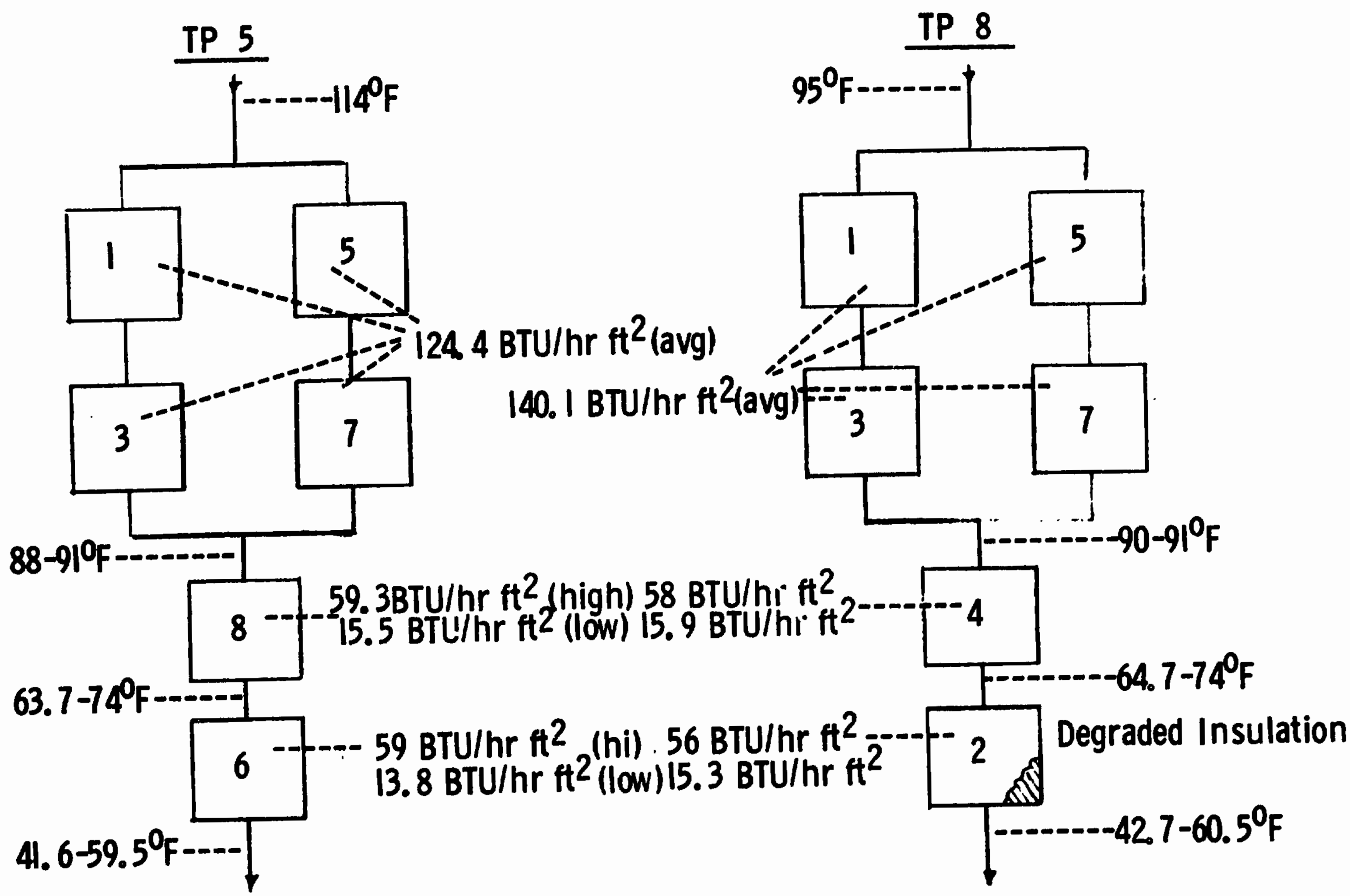


FIGURE 56

TEST POINT 21 - STABILIZED TEMPERATURES

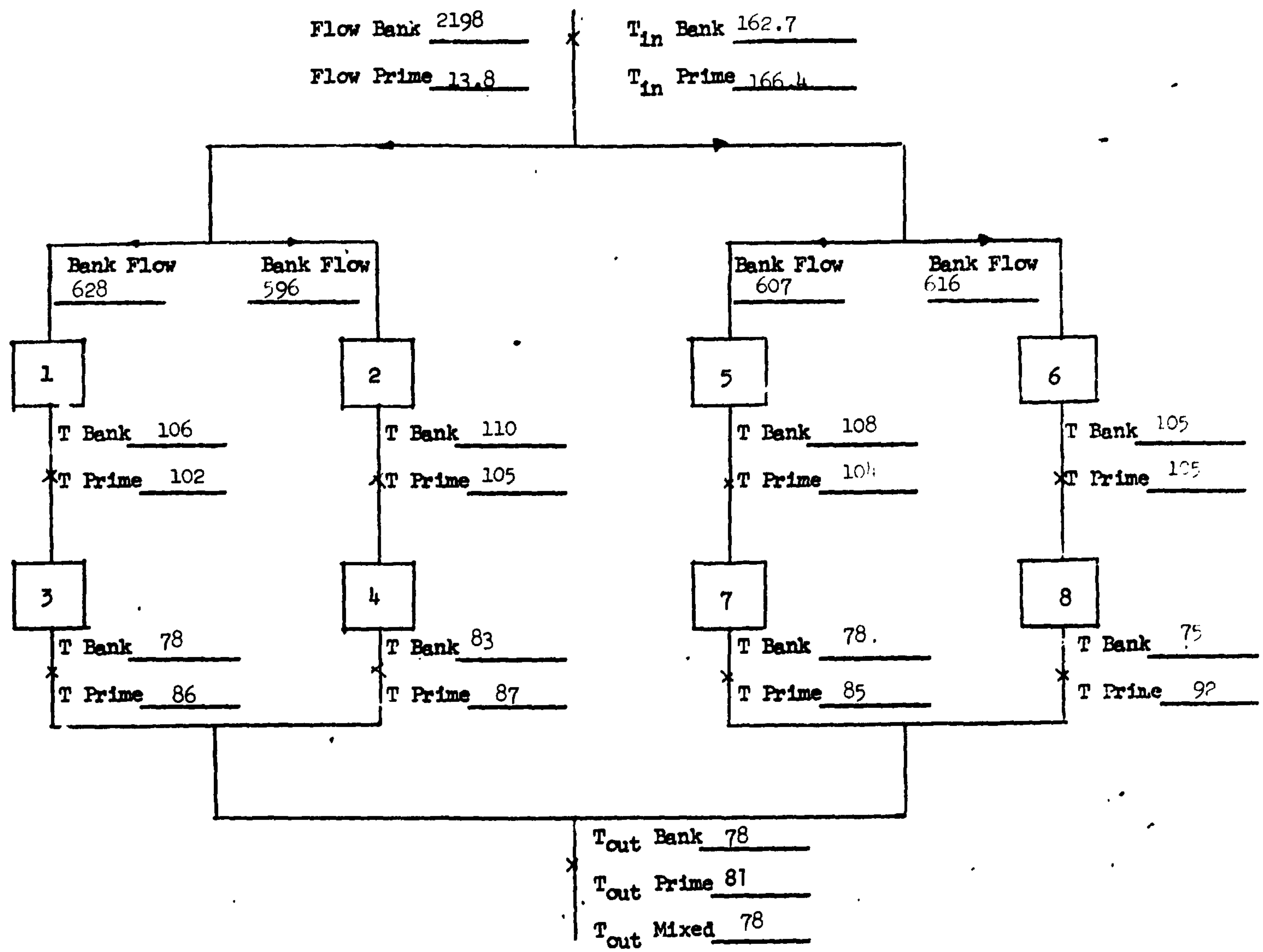


FIGURE 57
TEST POINT 22-1 - STABILIZED TEMPERATURES

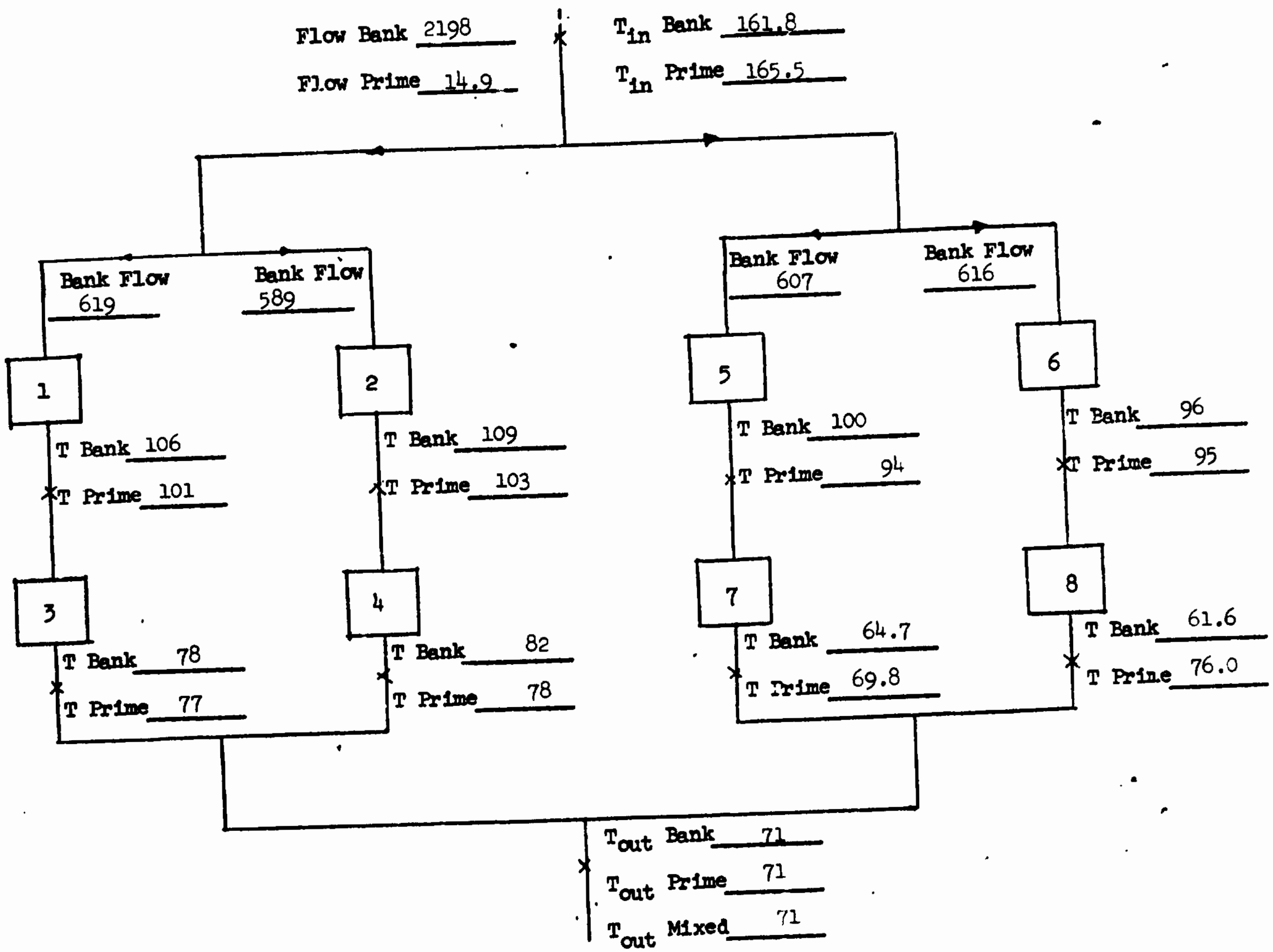


FIGURE 58

TEST POINT 22-2 - STABILIZED TEMPERATURES

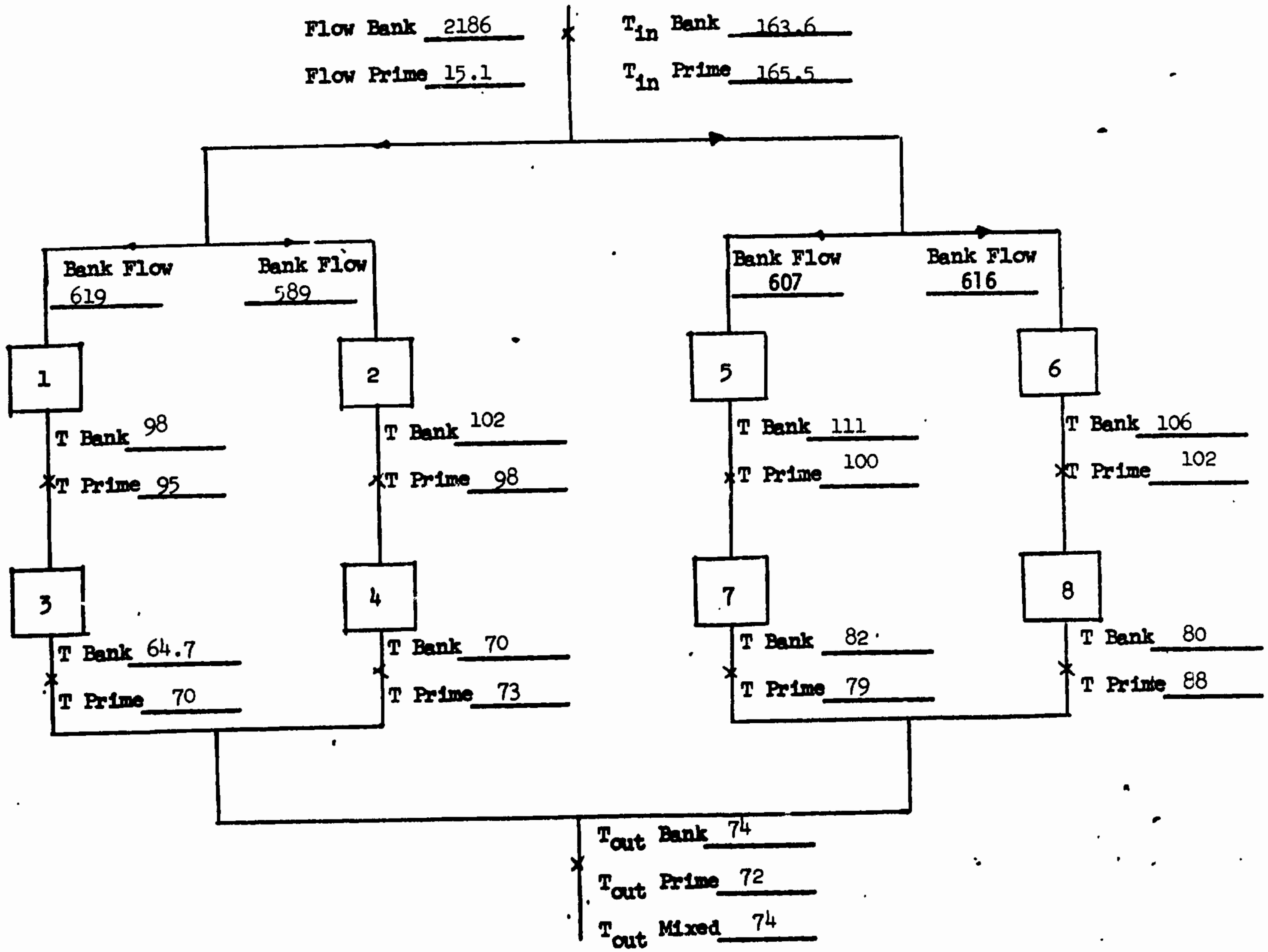


FIGURE 59

TEST POINT 22 - PANEL AND MIXED OUTLETS

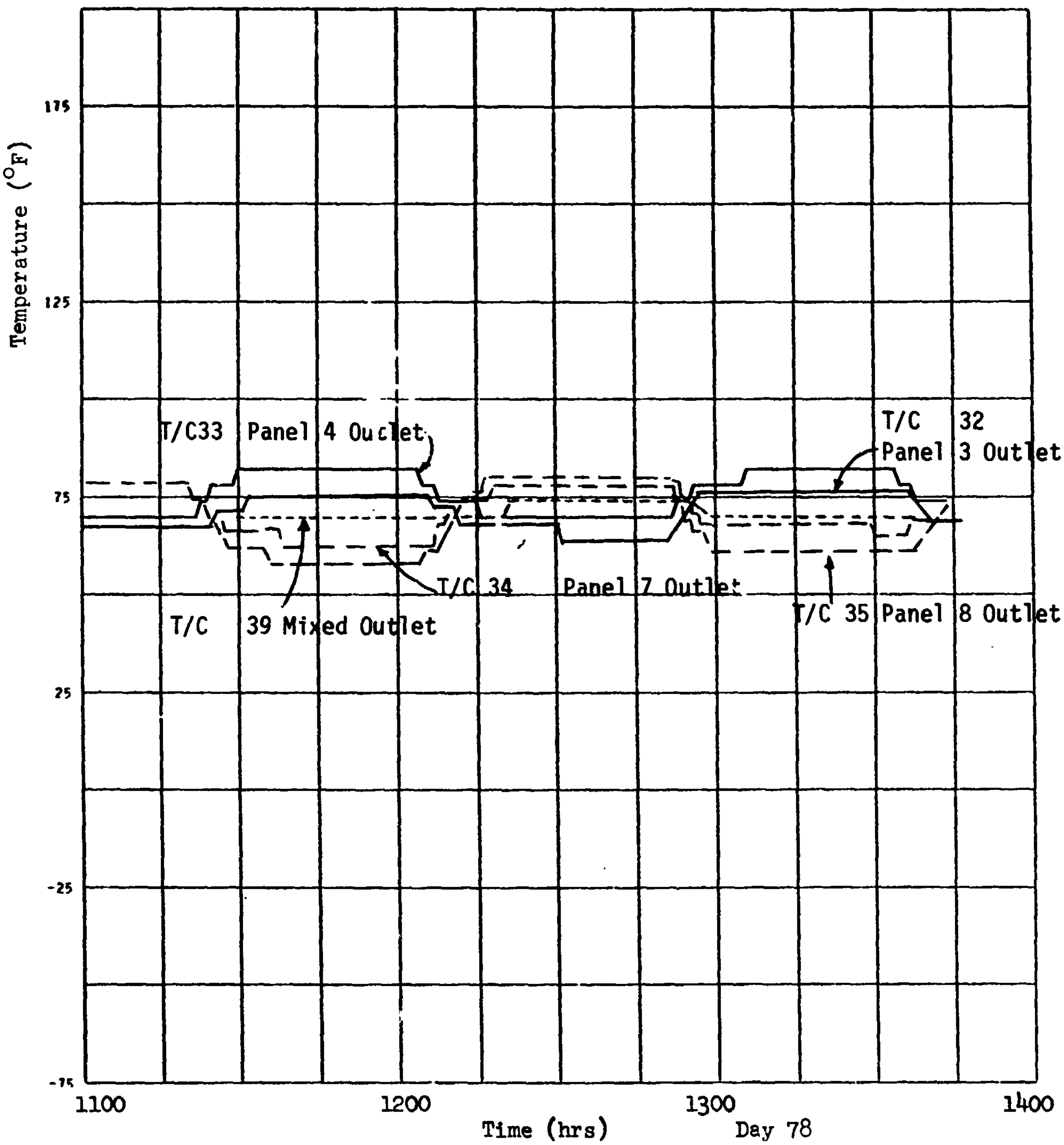


FIGURE 60

TEST POINT 23-1 - STABILIZED TEMPERATURES

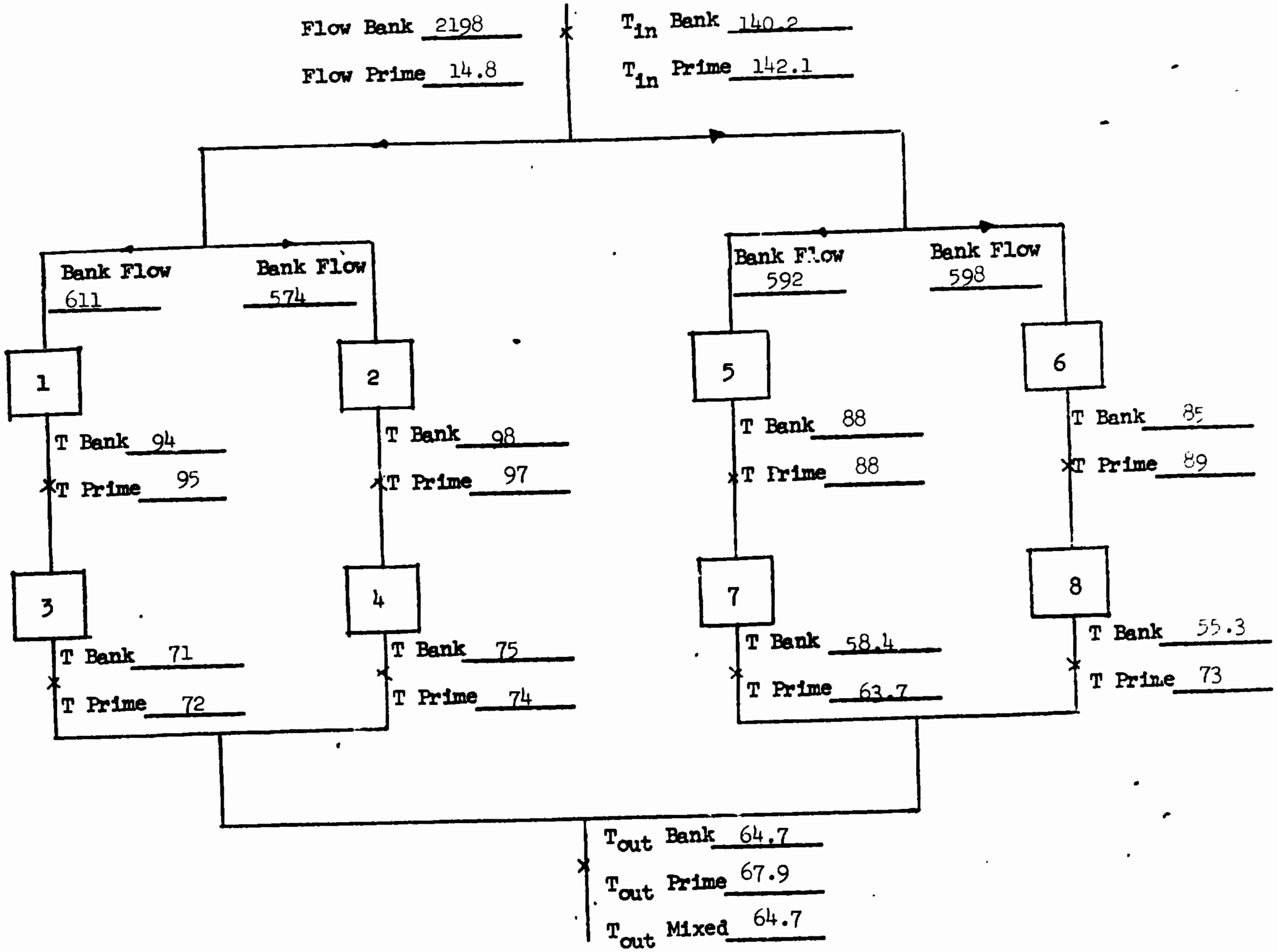


FIGURE 61

TEST POINT 23-2 - STABILIZED TEMPERATURES

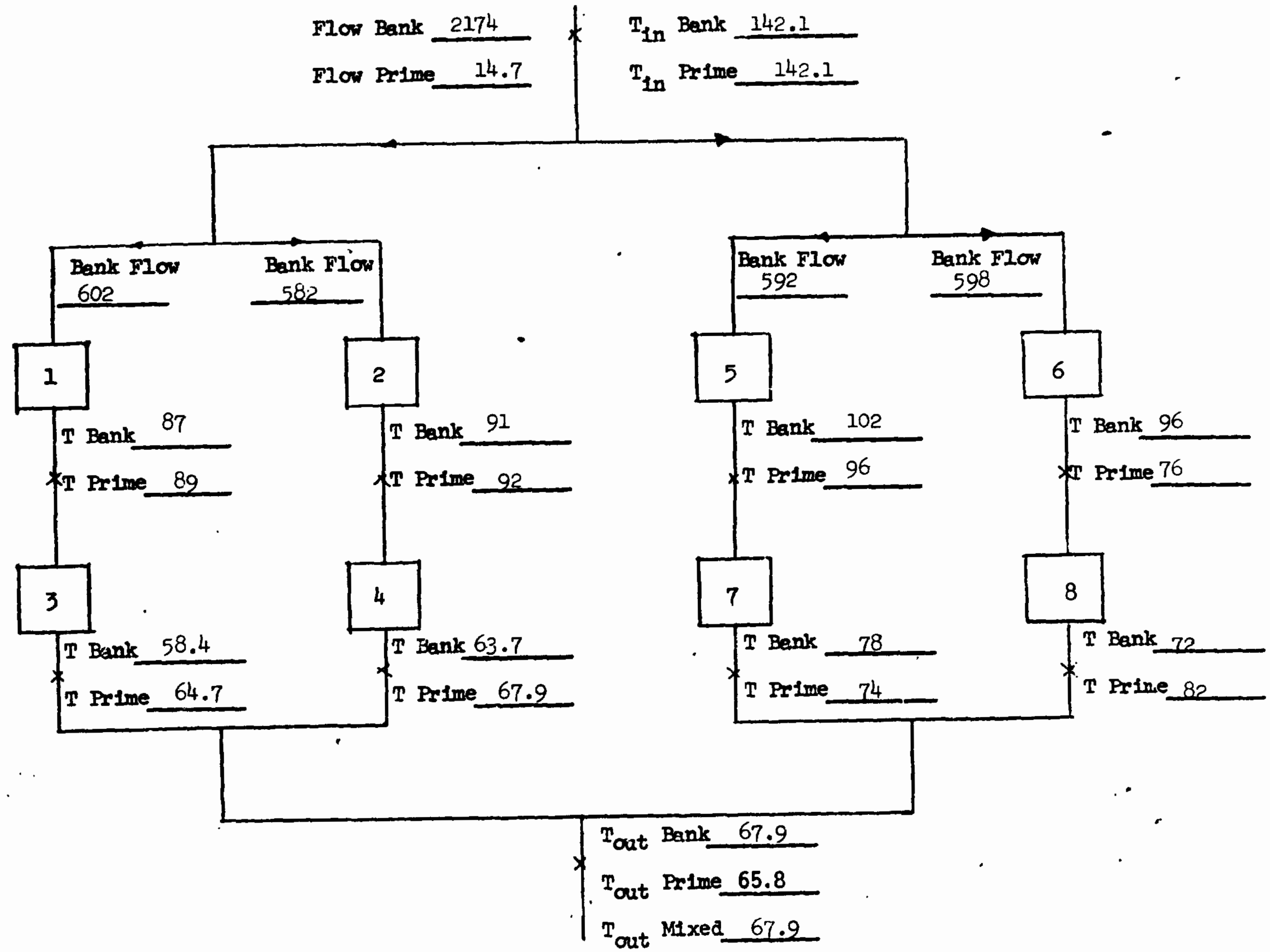


FIGURE 62
TEST POINT 23 - PANEL AND MIXED OUTLET
TEMPERATURES

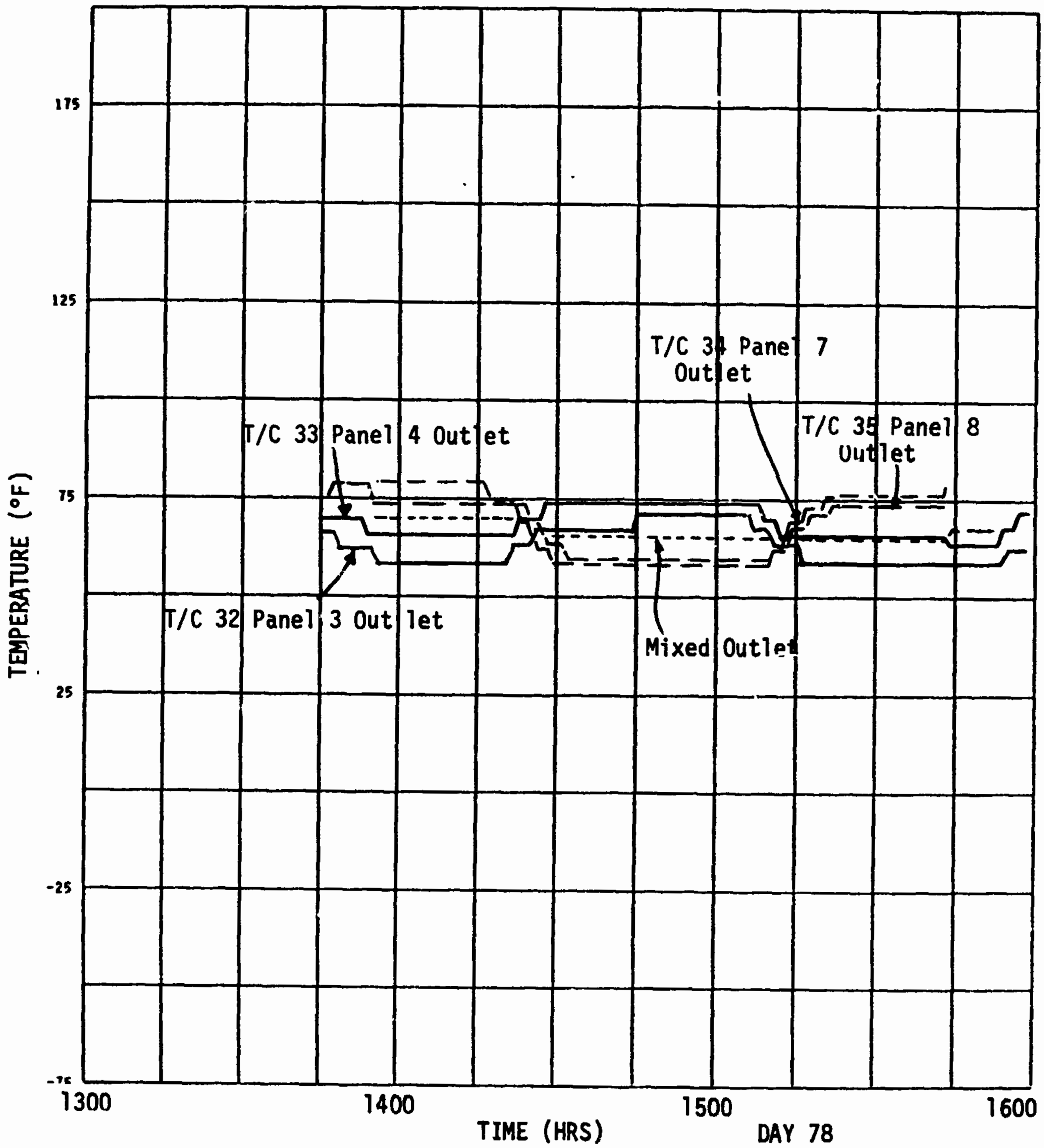


FIGURE 63

TEST POINT 24-1 - STABILIZED TEMPERATURES

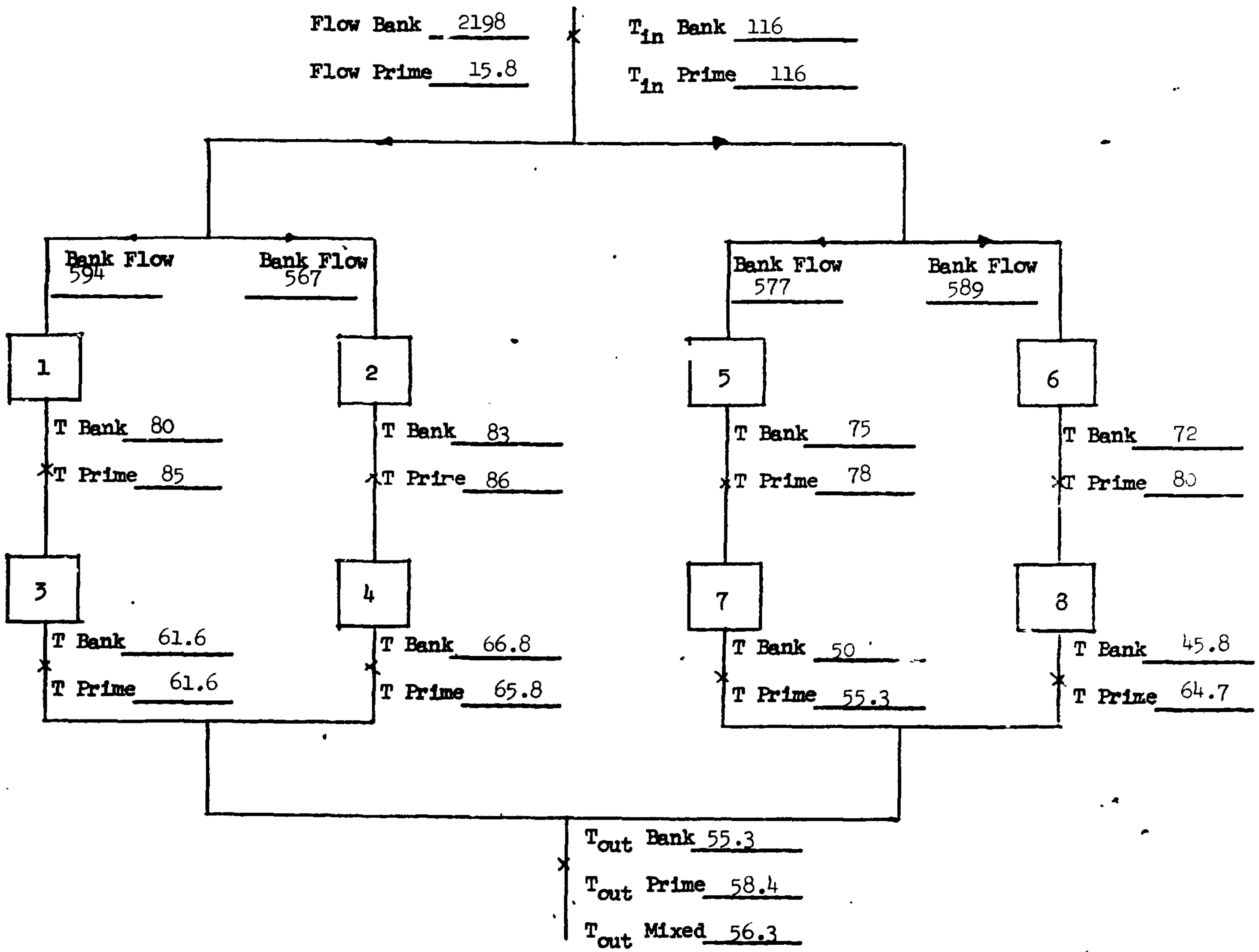


FIGURE 64

TEST POINT 24-2 - STABILIZED TEMPERATURES

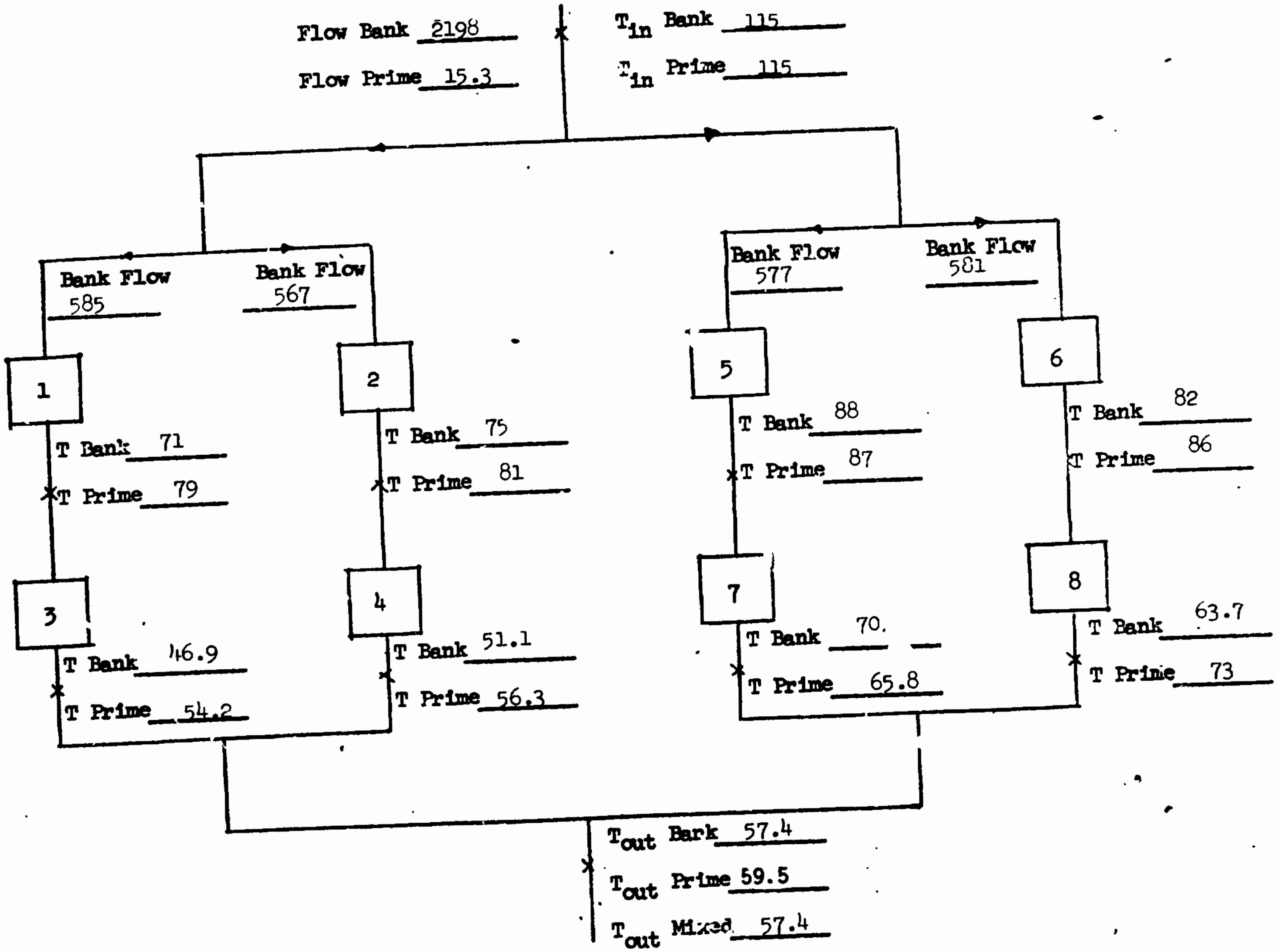


FIGURE 65

TEST POINT 25-1 - STABILIZED TEMPERATURES

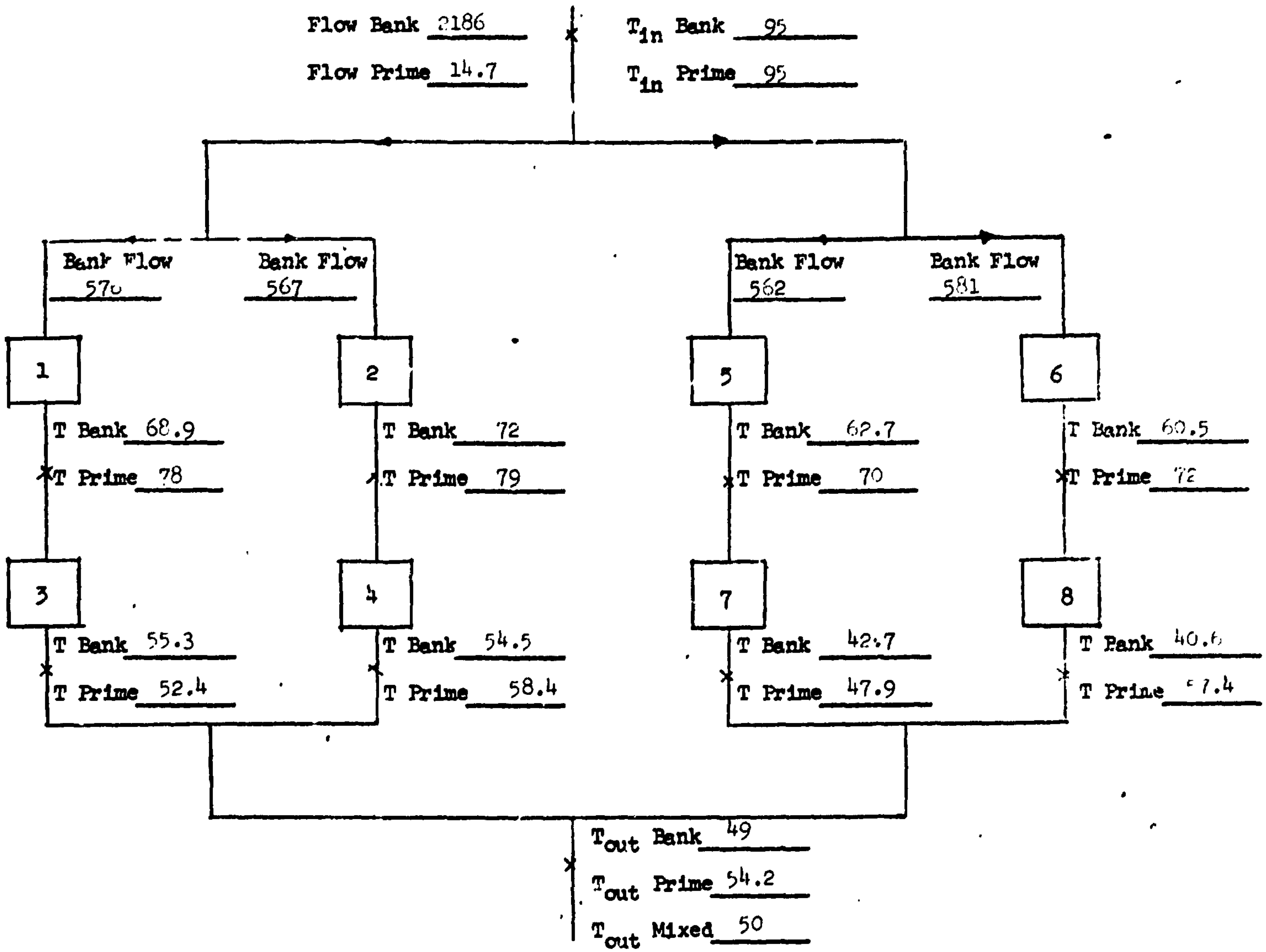


FIGURE 66

TEST POINT 25-2 - STABILIZED TEMPERATURES

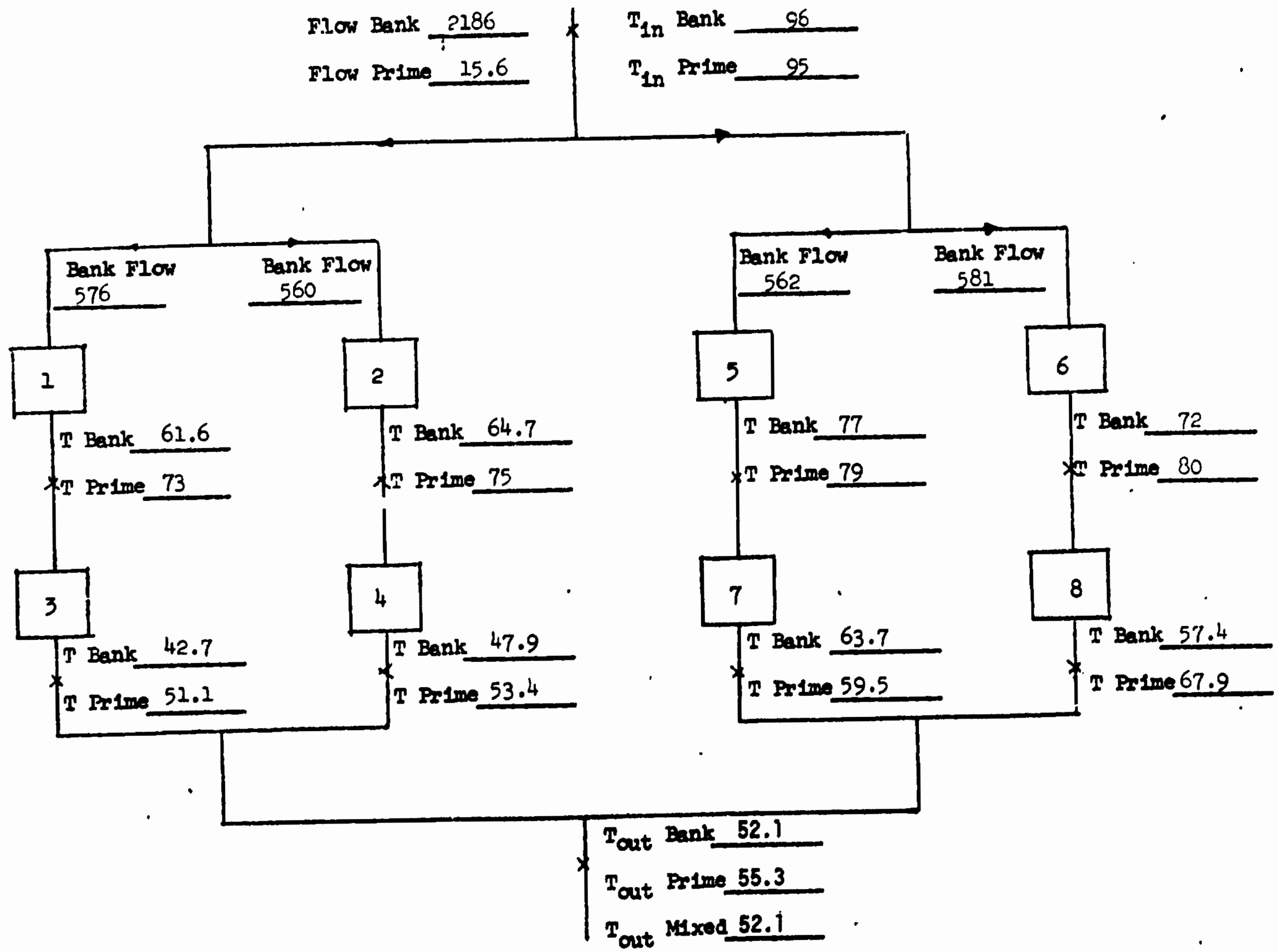


FIGURE 67

TEST POINT 26 - STABILIZED TEMPERATURES

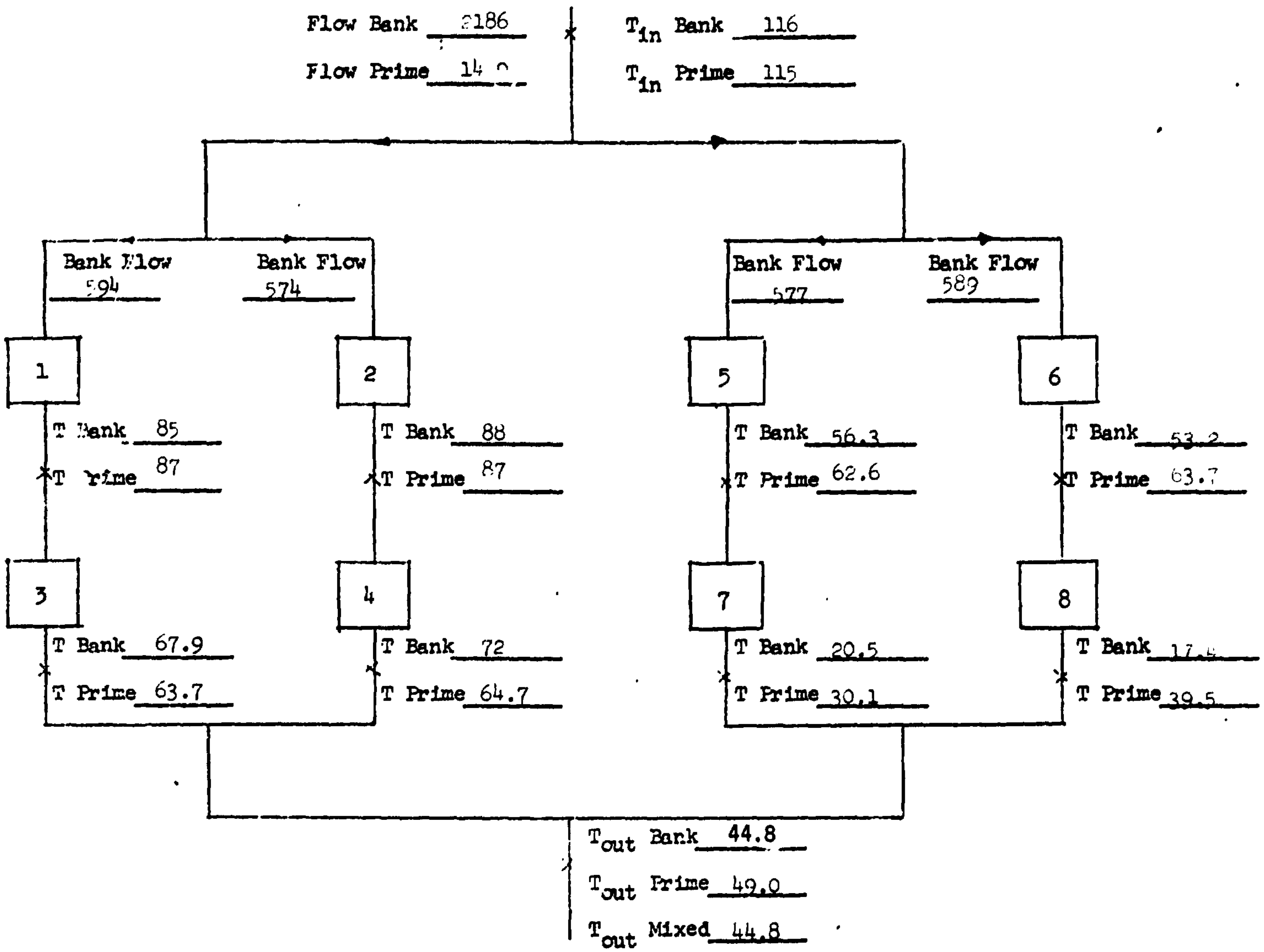


FIGURE 68

TEST POINT 27 - STABILIZED TEMPERATURES

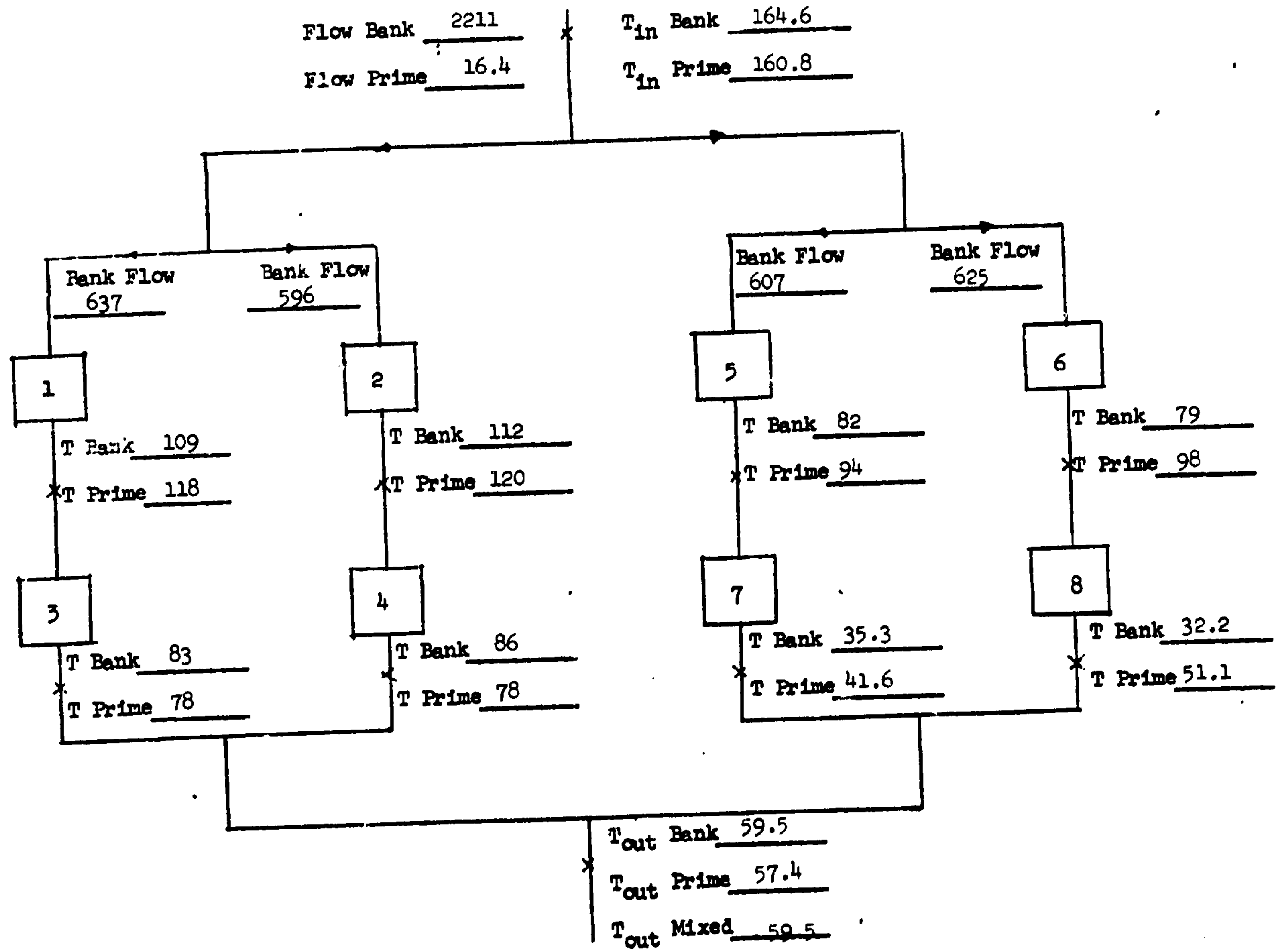


FIGURE 69

TEST POINT 28 - STABILIZED TEMPERATURES

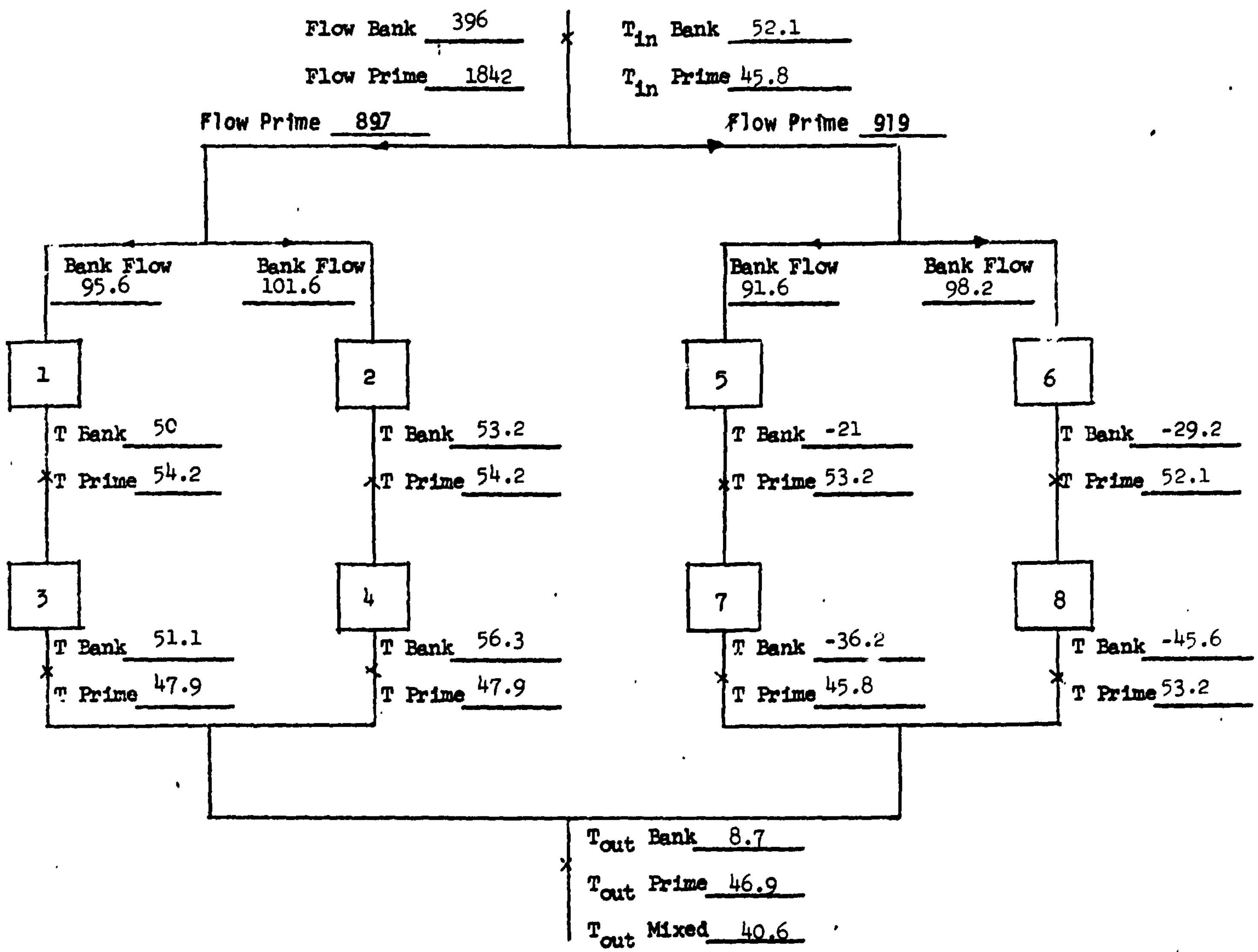


FIGURE 70

TEST POINT 29-1 - STABILIZED TEMPERATURES

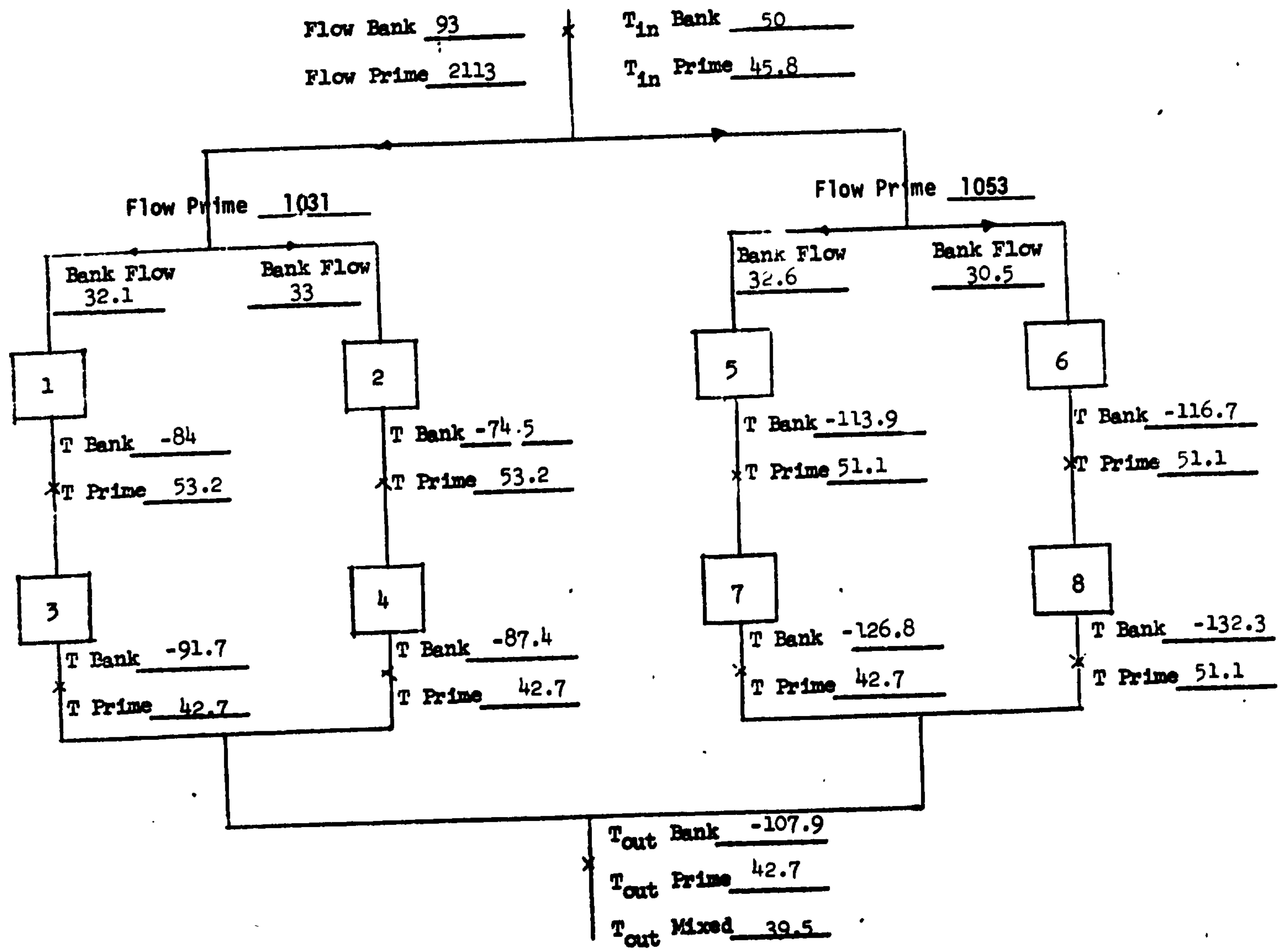


FIGURE 71

TEST POINT 29-2 - STABILIZED TEMPERATURES

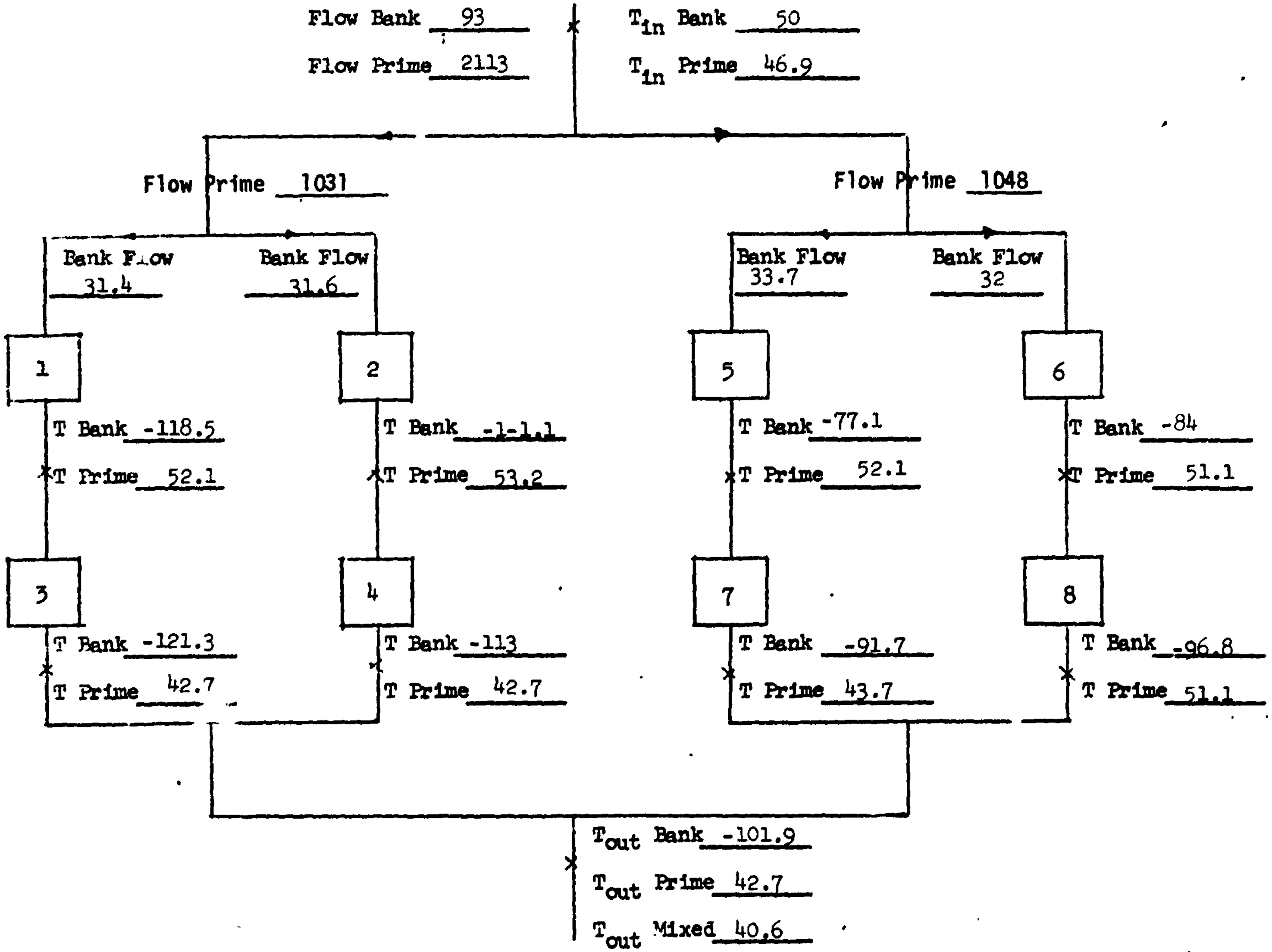


FIGURE 72

TEST POINT 61 - FLOW RATES

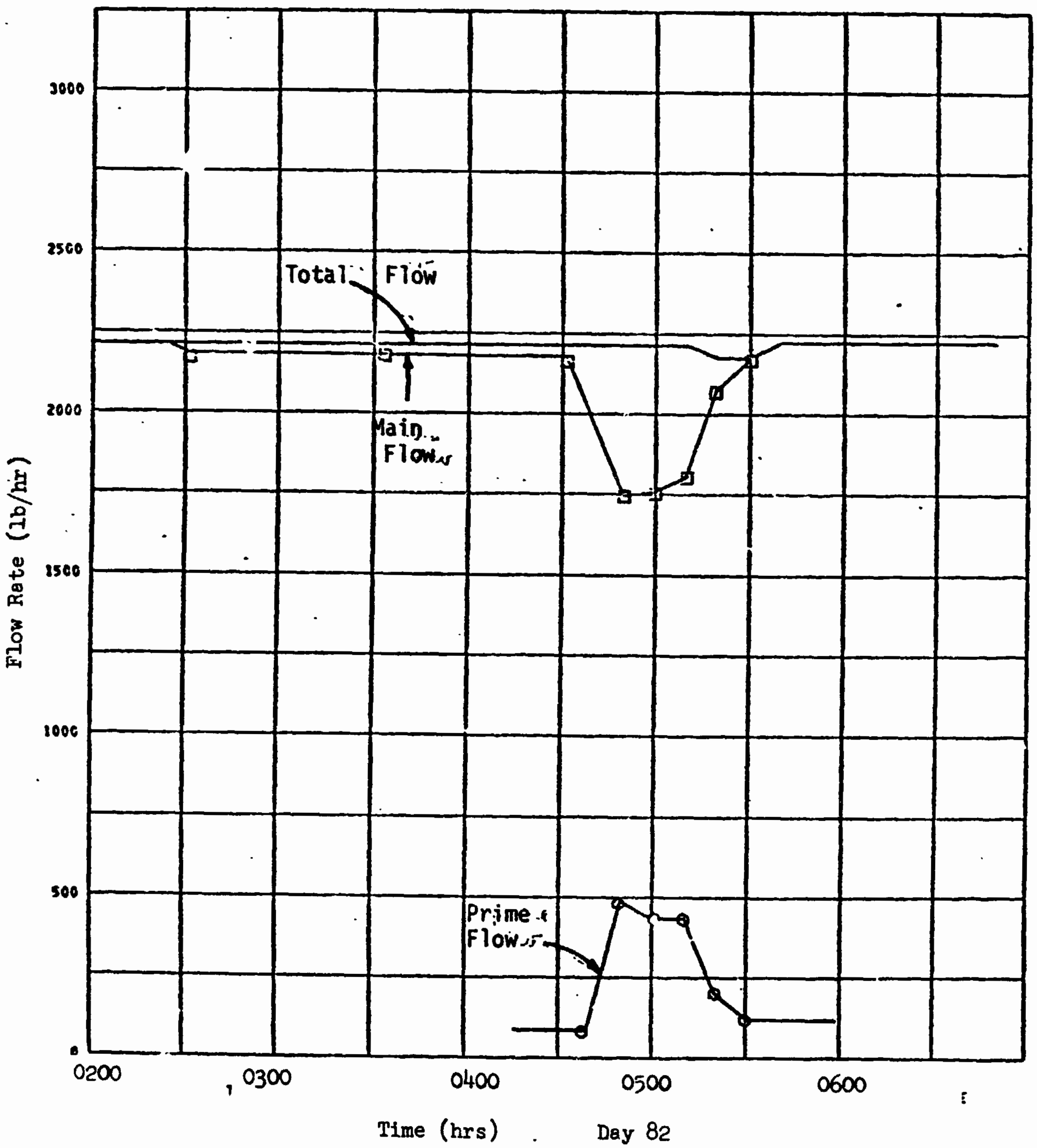
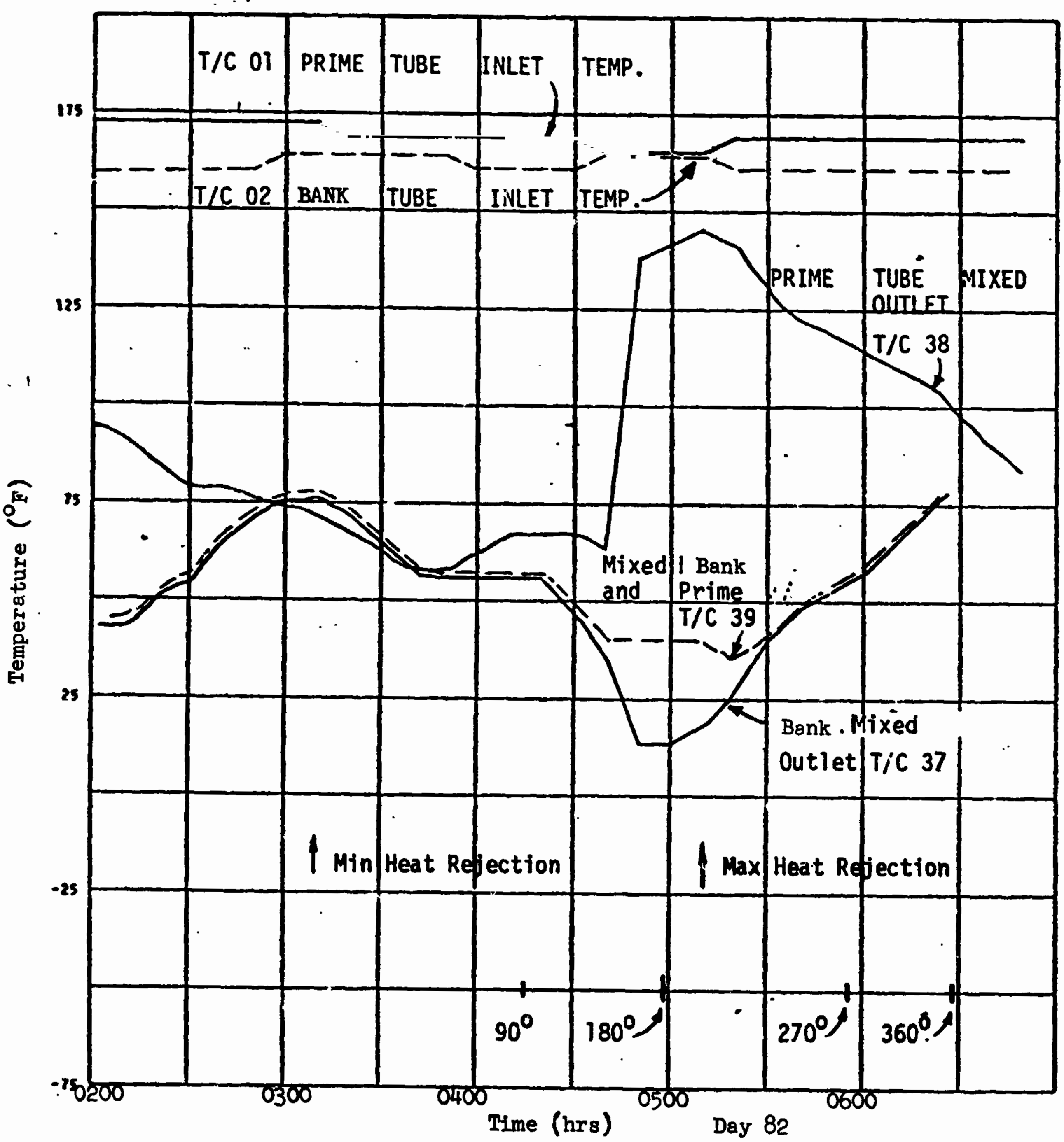


FIGURE 73

TEST POINT 61 - PRIME, BANK, MIXED
OUTLET TEMPERATURE



E

FIGURE 74

TEST POINT 63 - FLOWRATES

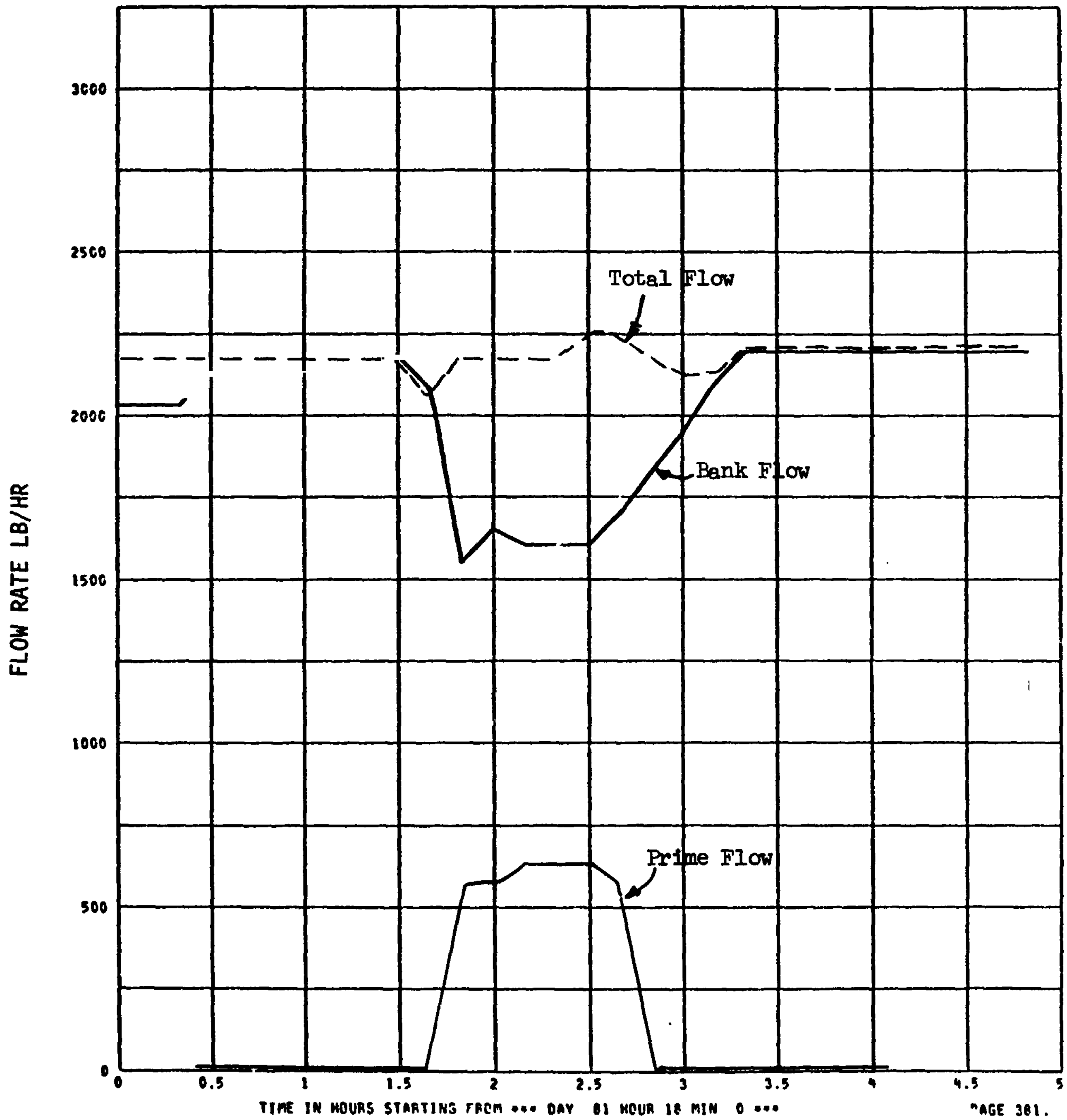


FIGURE 75

TEST POINT 63 - PRIME, BANK AND MIXED OUTLET TEMPERATURES

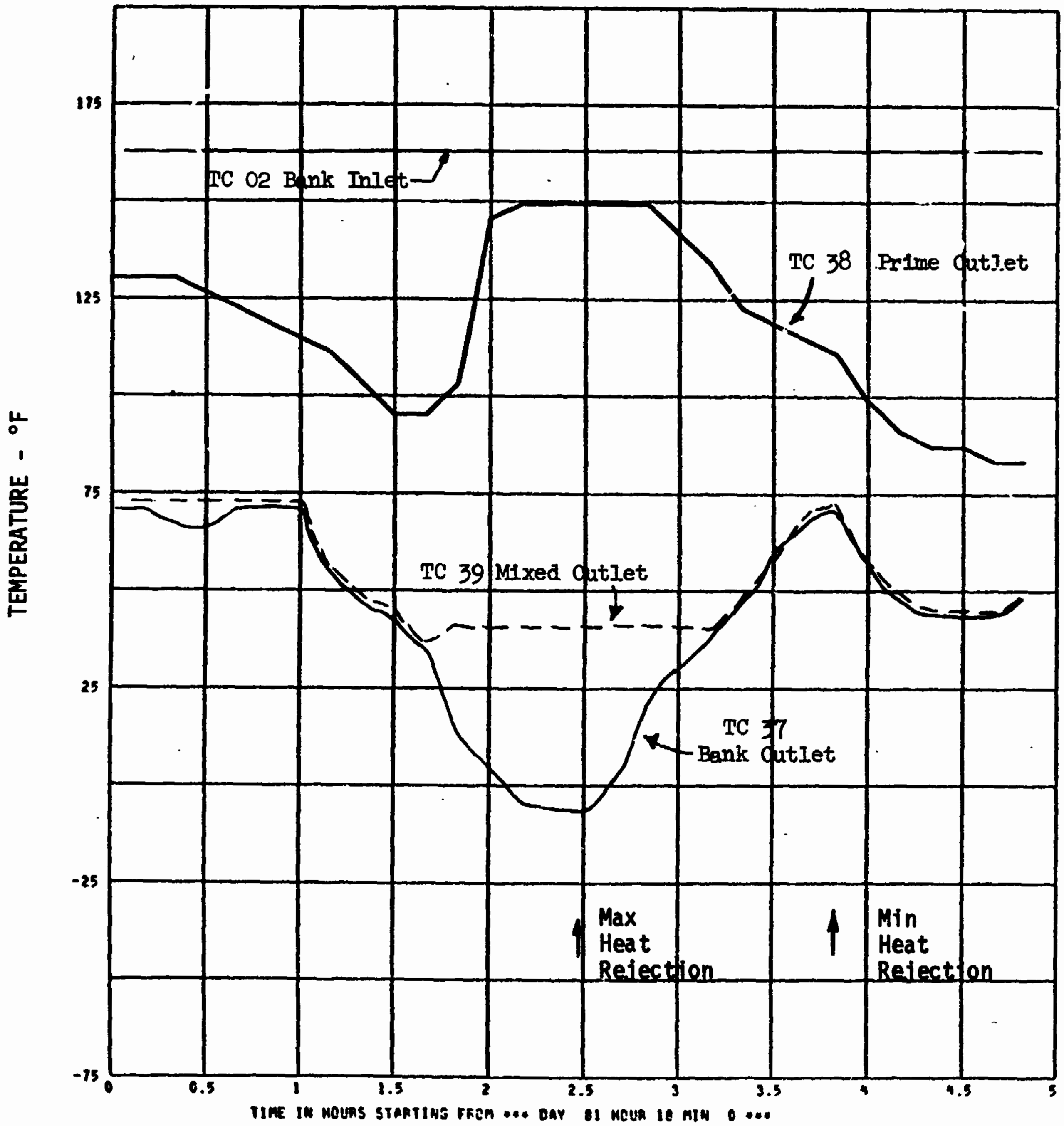


FIGURE 76

TEST POINT 64 - FLOW RATES

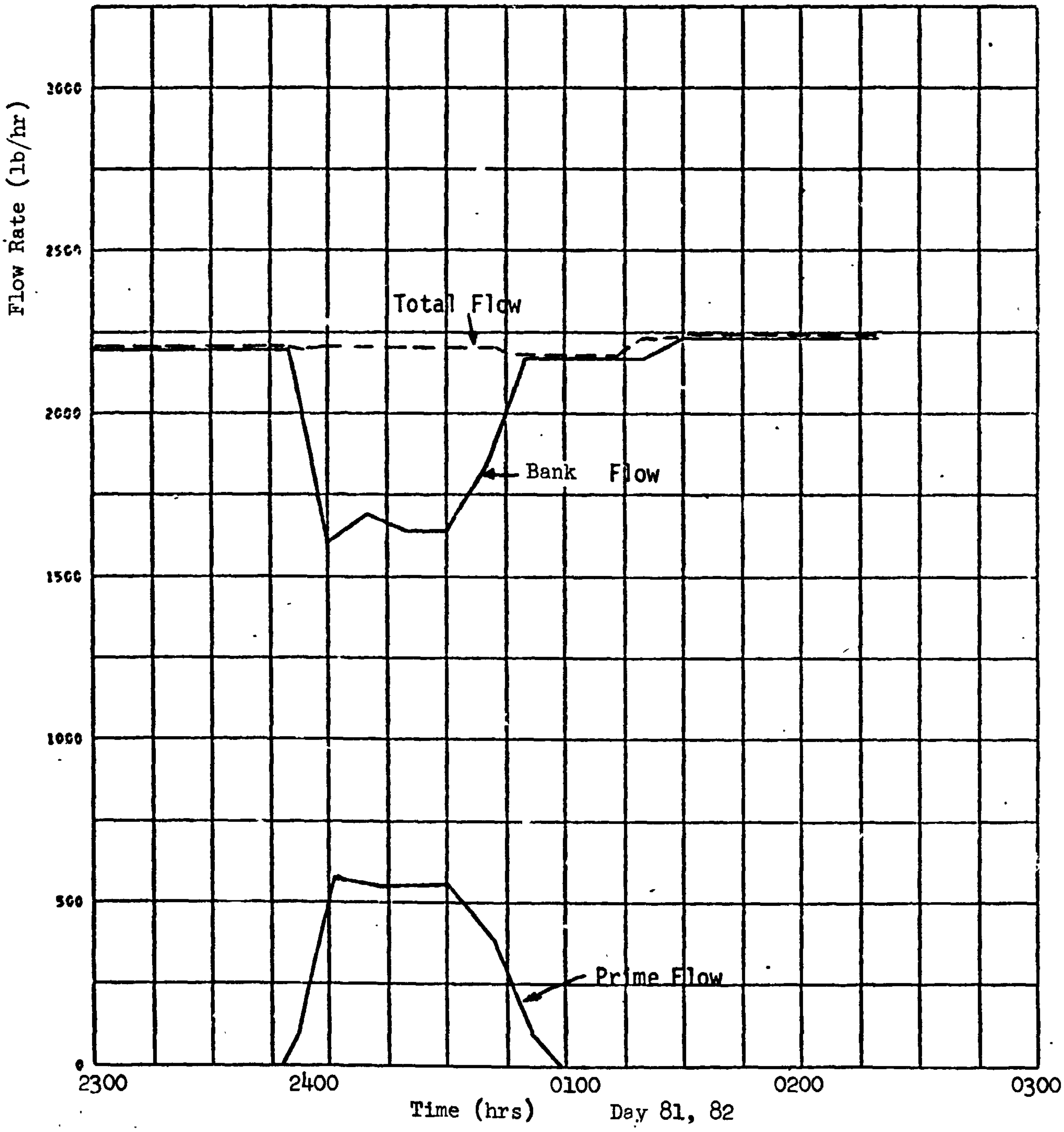


FIGURE 77

TEST POINT 64 - PRIME, BANK, MIXED
OUTLET TEMPERATURES

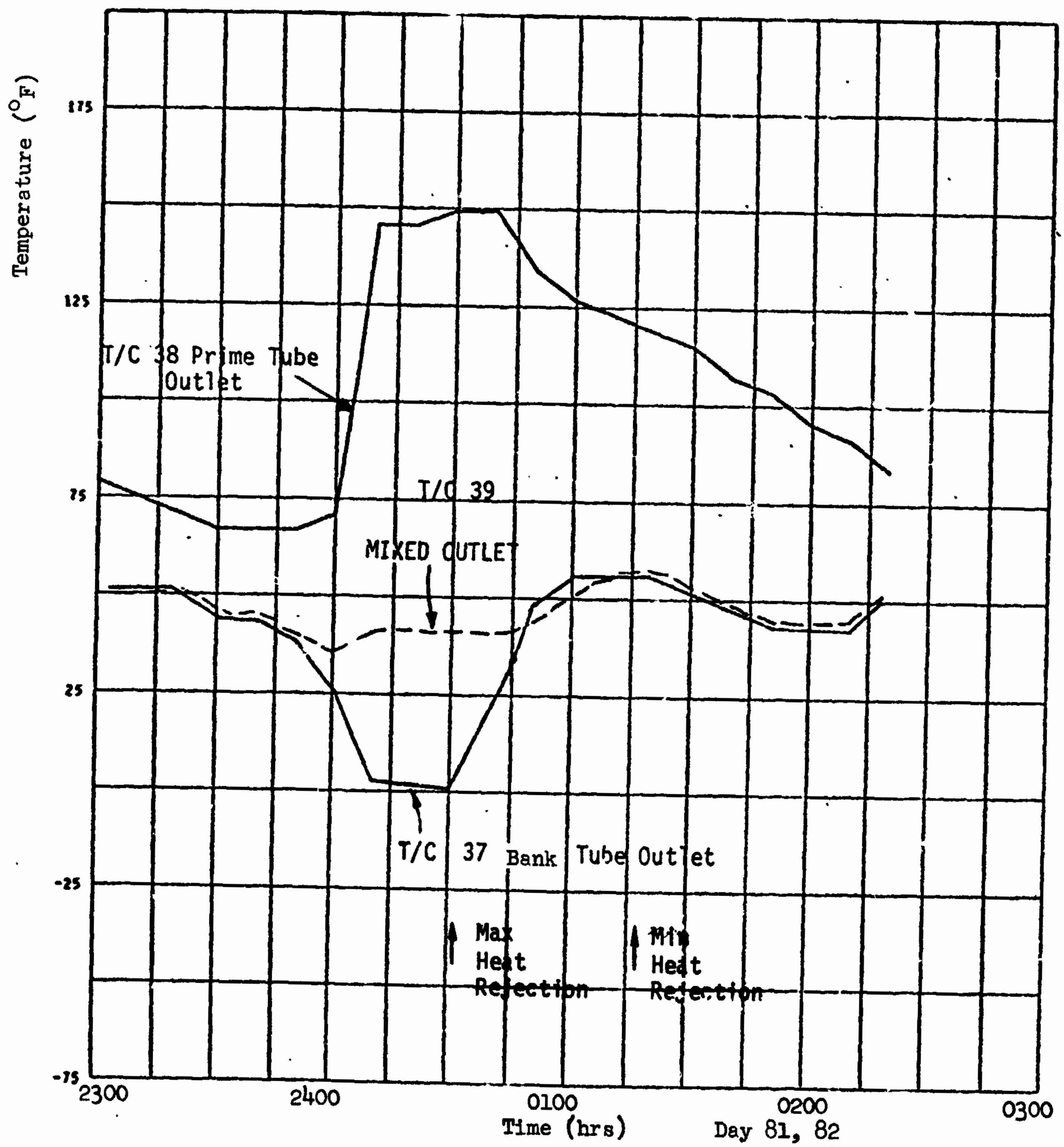


FIGURE 78
TEST GROUP 2.5 - RESPONSE TO
SET POINT CHANGES

LOW LOAD (T_{in} = 53°F) COLD ENVIR.

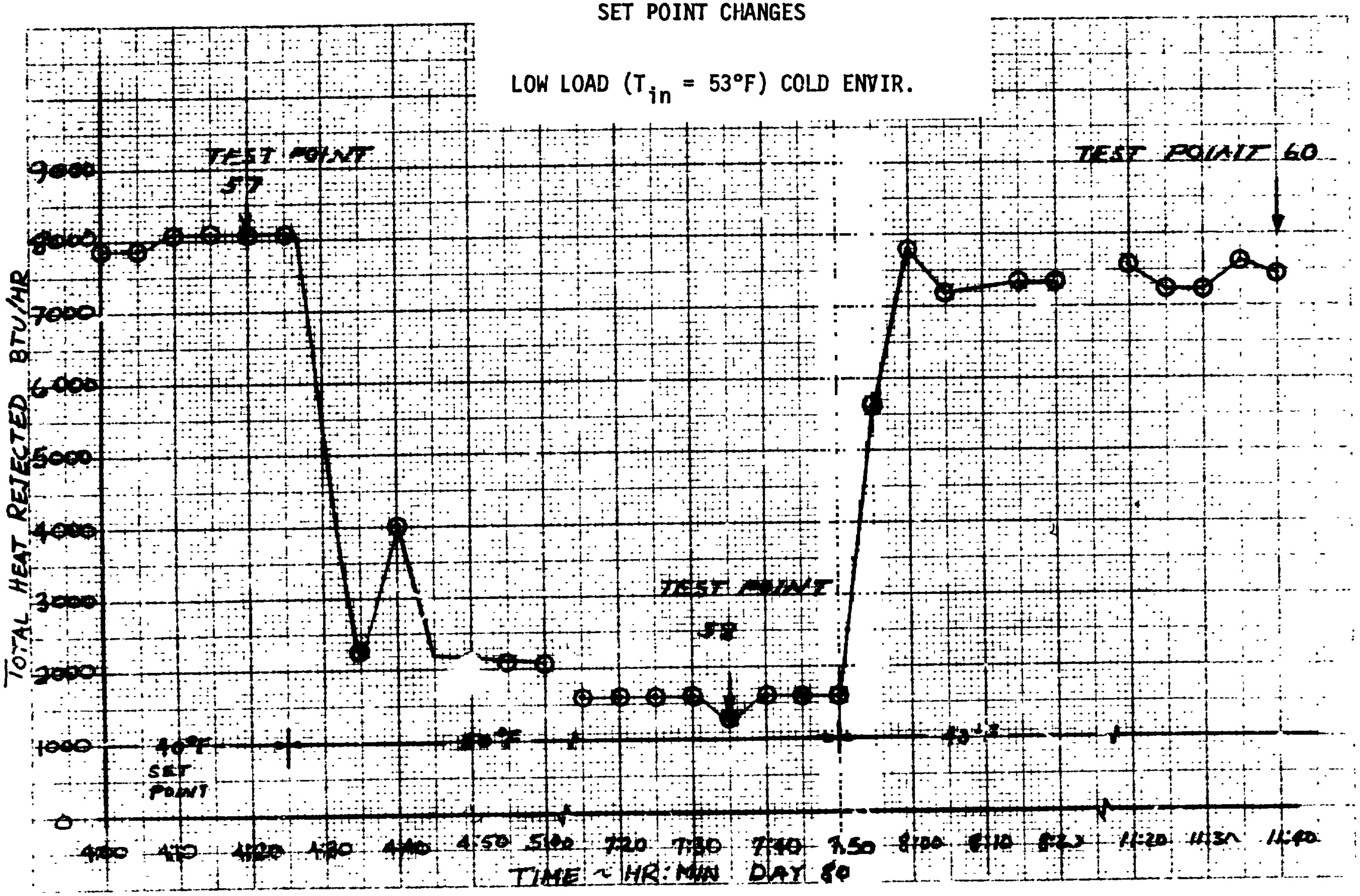


FIGURE 79

TEST GROUP 2.6-RESPONSE
TO SET POINT CHANCES

HIGH LOAD (T_{in} = 159°F) COLD ENVIRONMENT

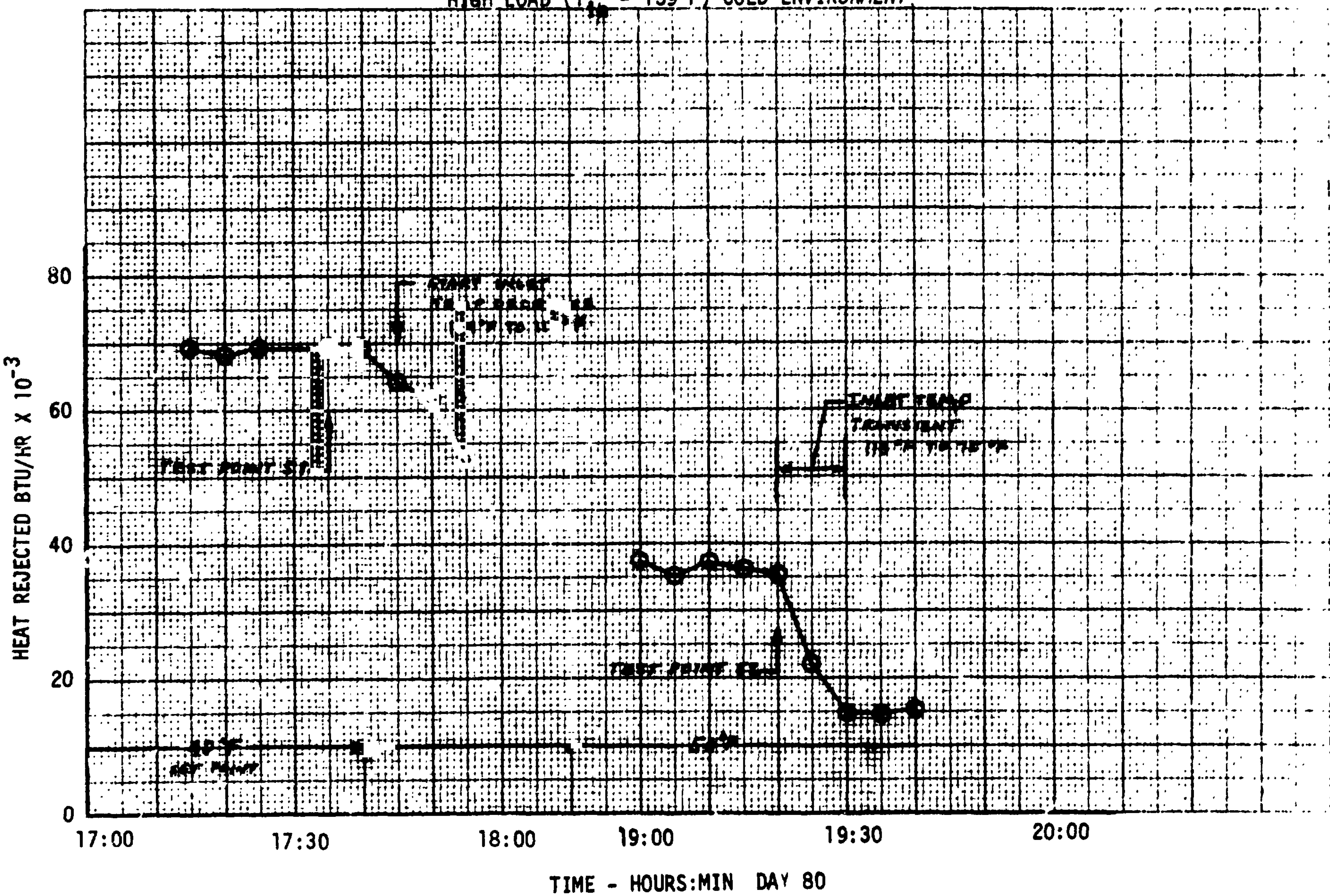


FIGURE 80 - TEST GROUP 2.7-RESPONSE TO SET POINT CHANGES
INTERMEDIATE LOAD (T_{in} = 75°F) COLD ENVIR.

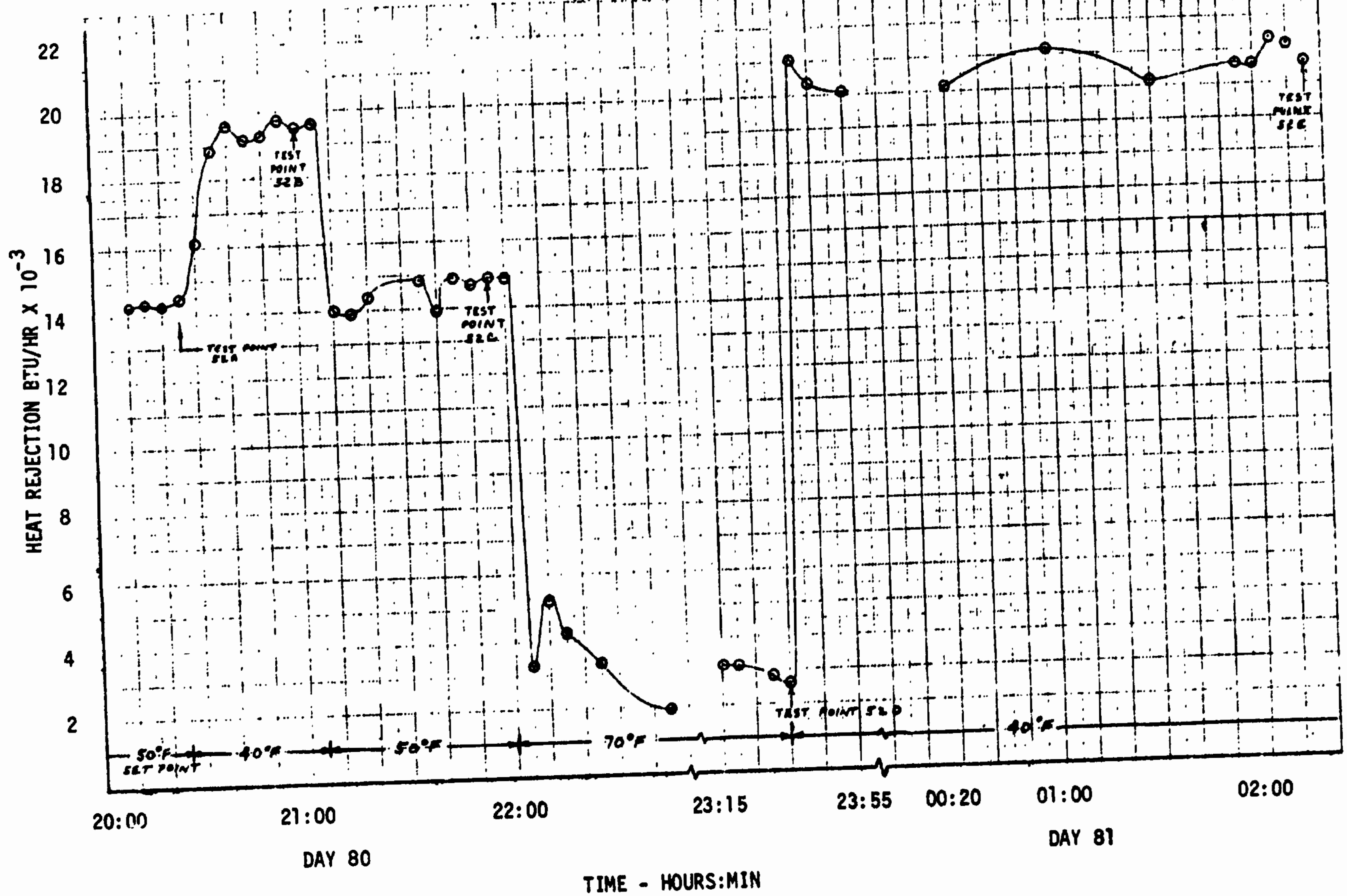


FIGURE 81

TEST GROUP 2.8 - RESPONSE TO SET POINT CHANGES

HIGH LOAD (T_{in} = 163°F) SKEWED ENVIRONMENT

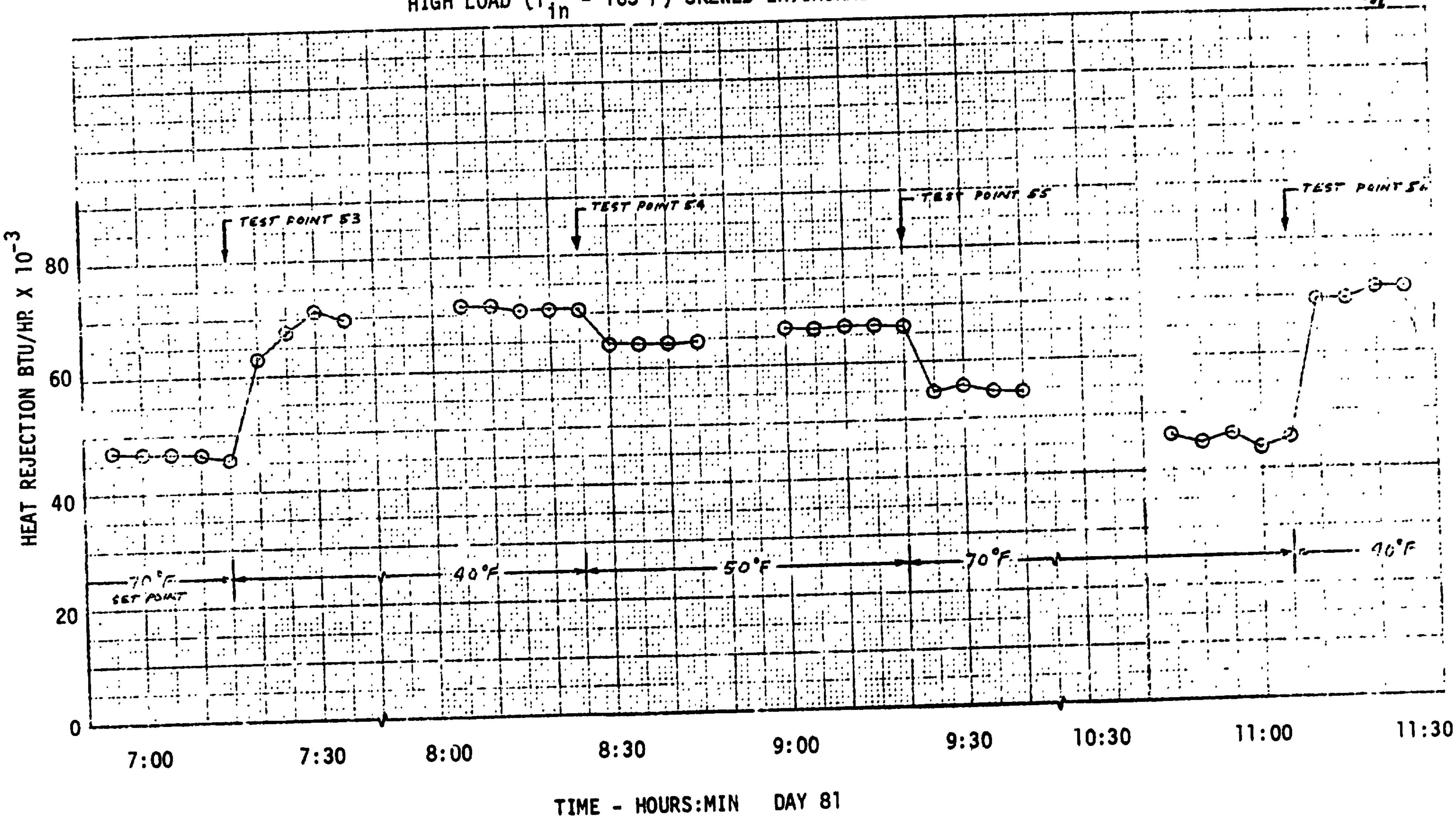


FIGURE 82

TEST GROUP 2.5 FLOW AND TEMPERATURES RESPONSE TO SET POINT CHANGES

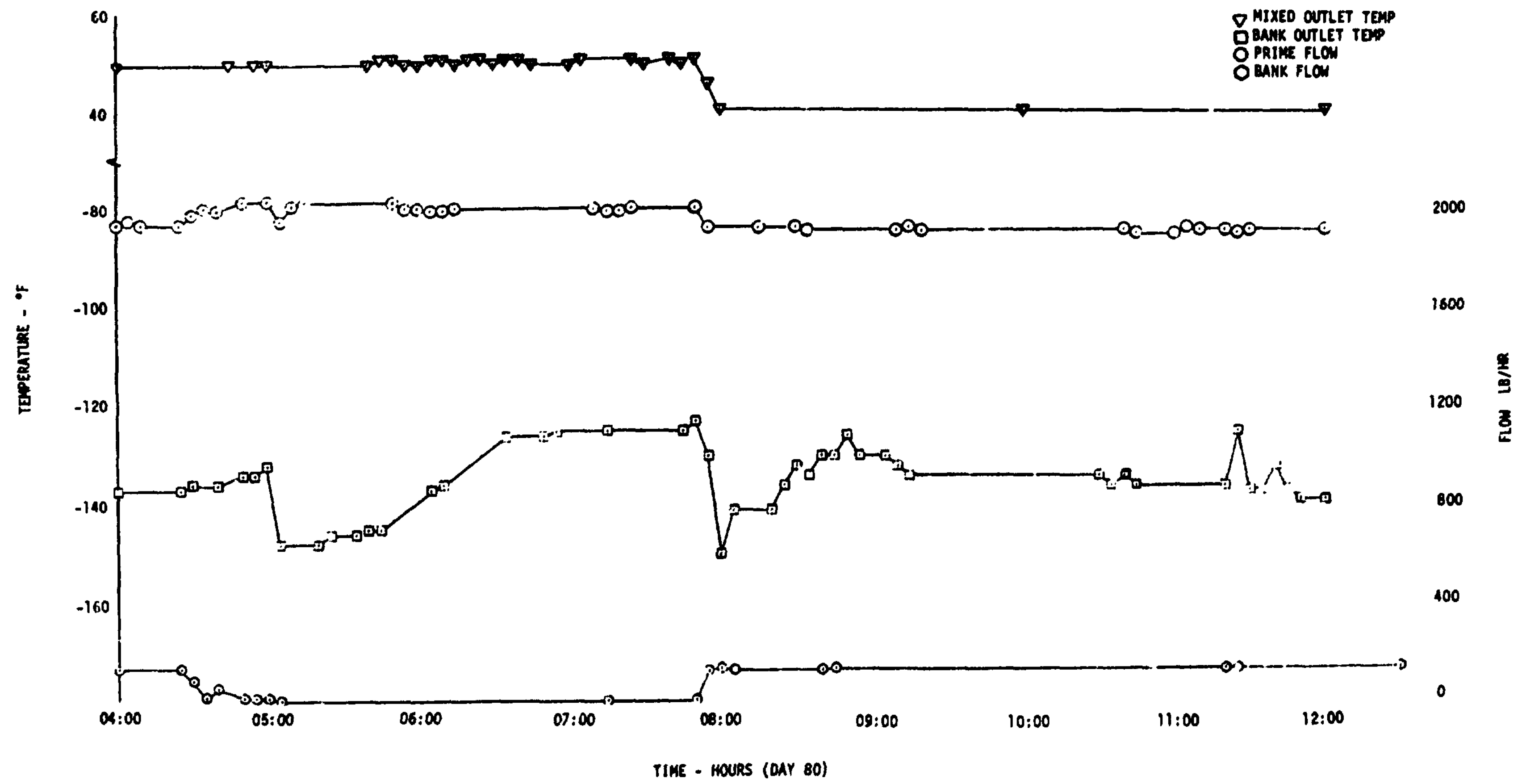


FIGURE 83

TEST GROUP 2.6 - FLOW AND TEMPERATURE
RESPONSE TO SET POINT CHANGES

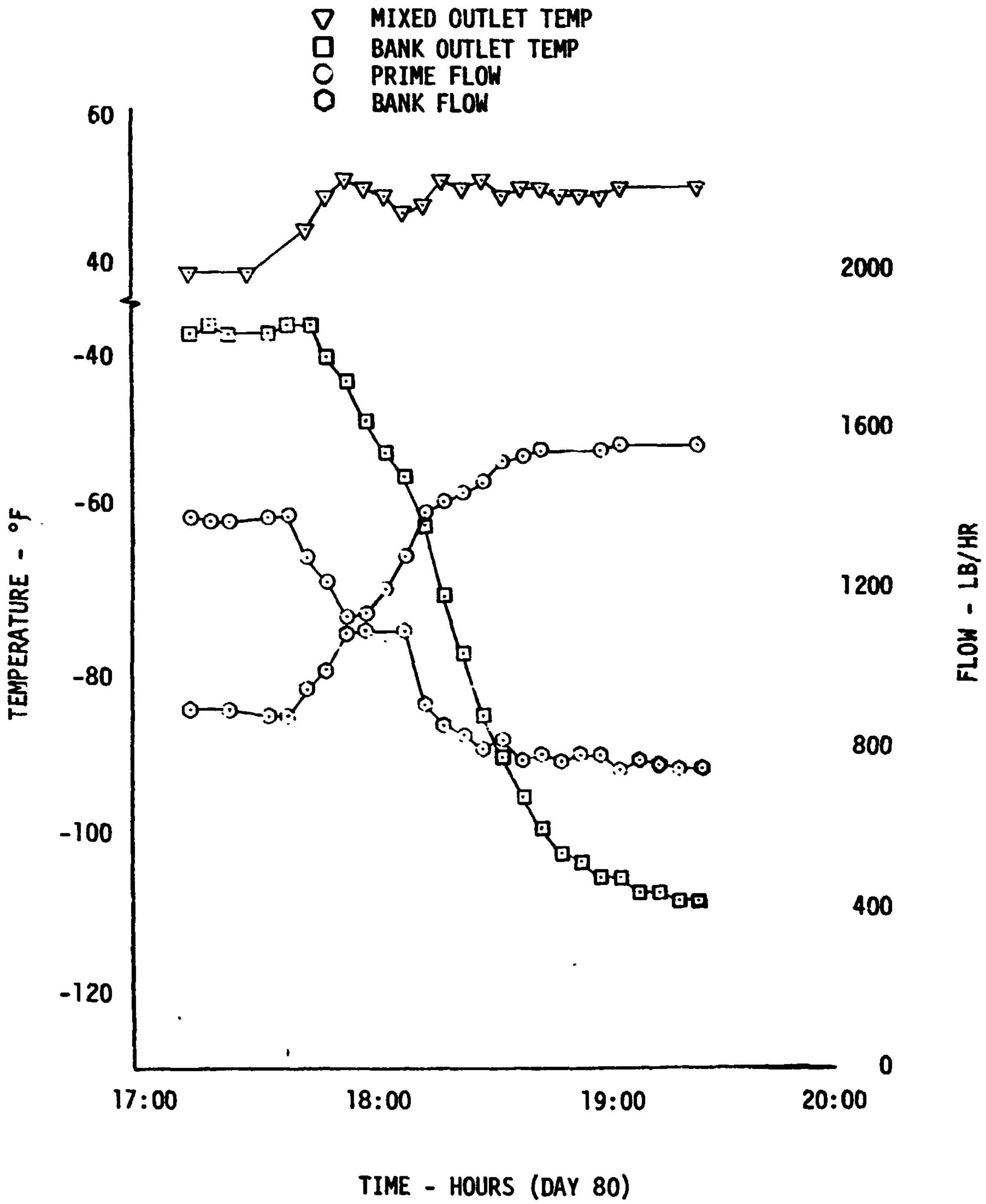


FIGURE 84

TEST GROUP 2.7 FLOW AND TEMPERATURE RESPONSE TO SET POINT CHANGES

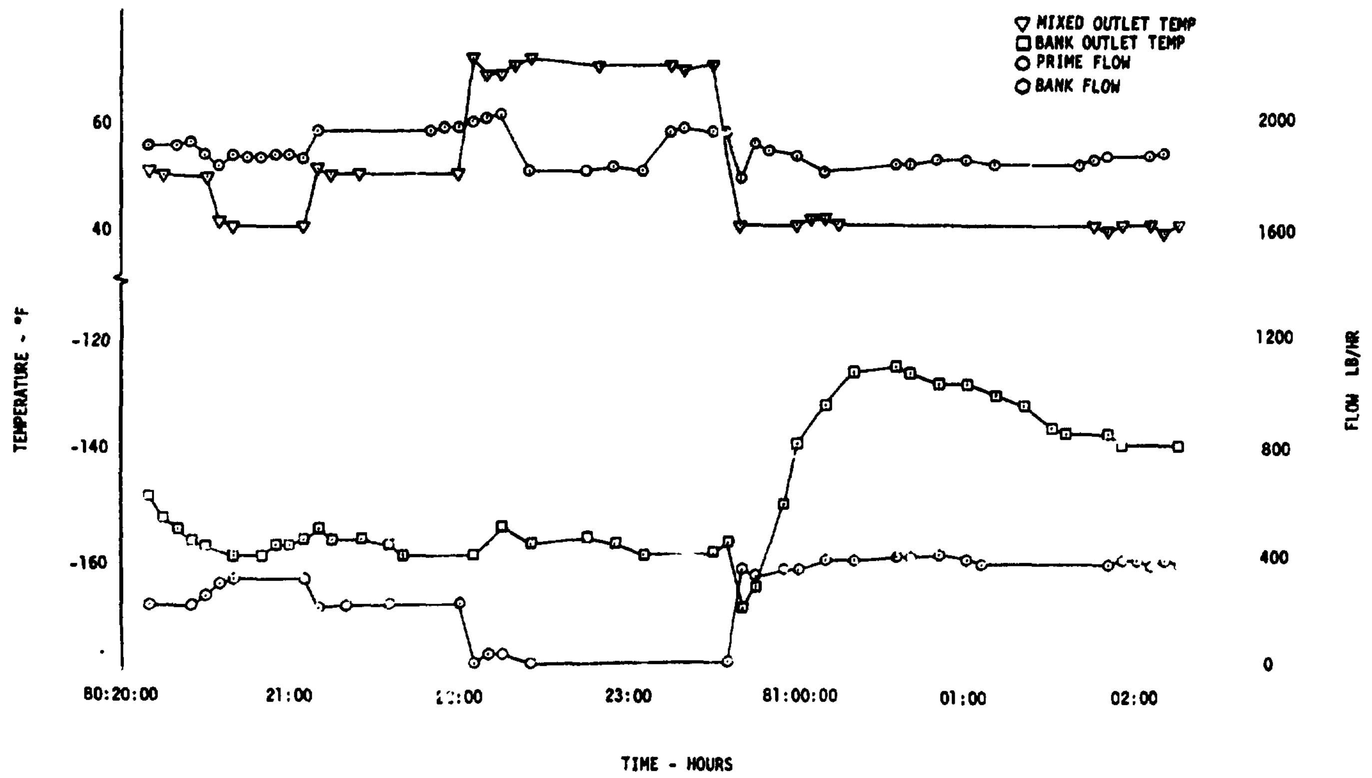


FIGURE 85

TEST GROUP 2.8 - FLOW AND TEMPERATURE RESPONSE TO SET POINT CHANGES

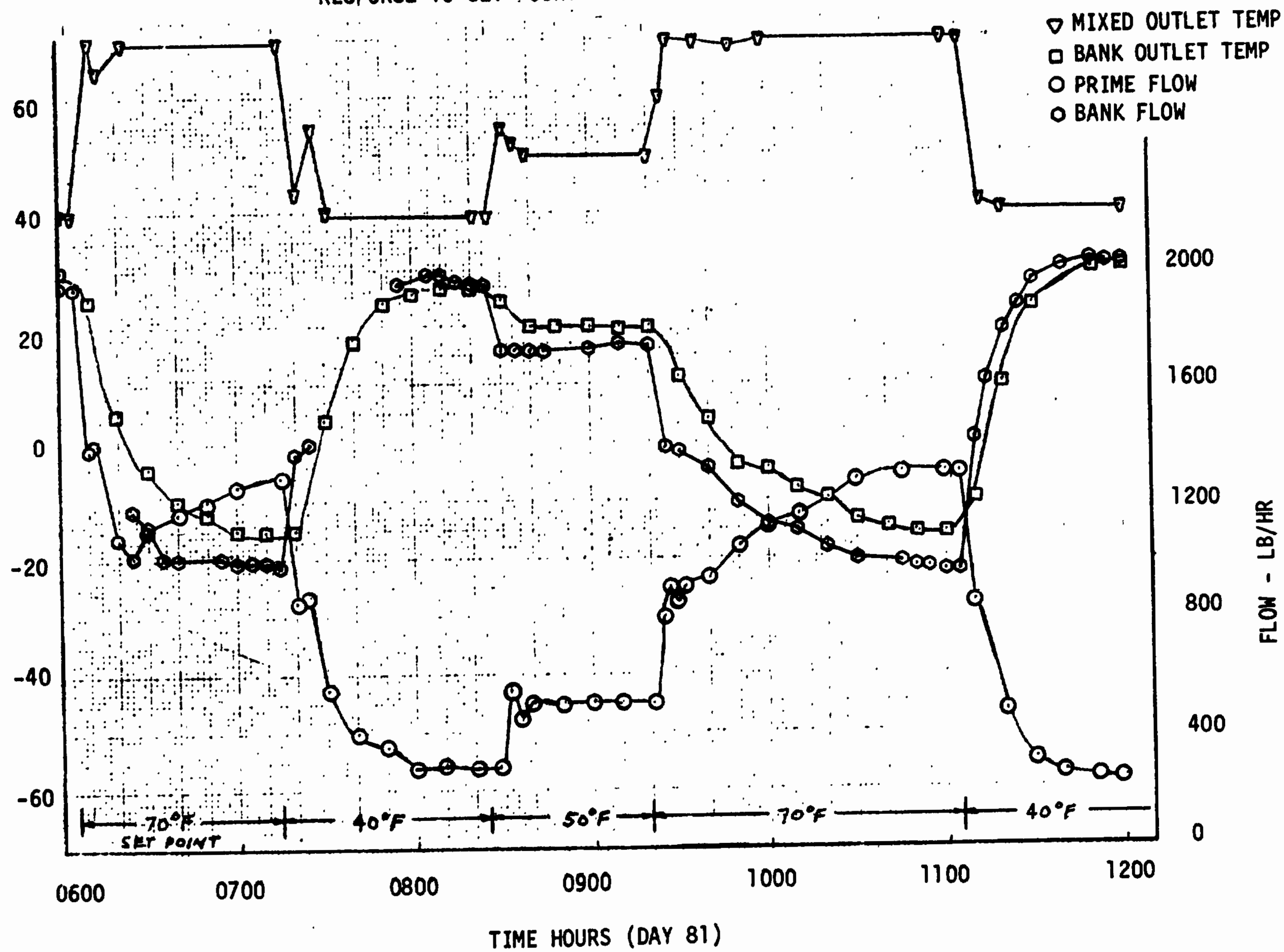


FIGURE 86

TEST POINTS 52D, E - PANEL FLOW RATES

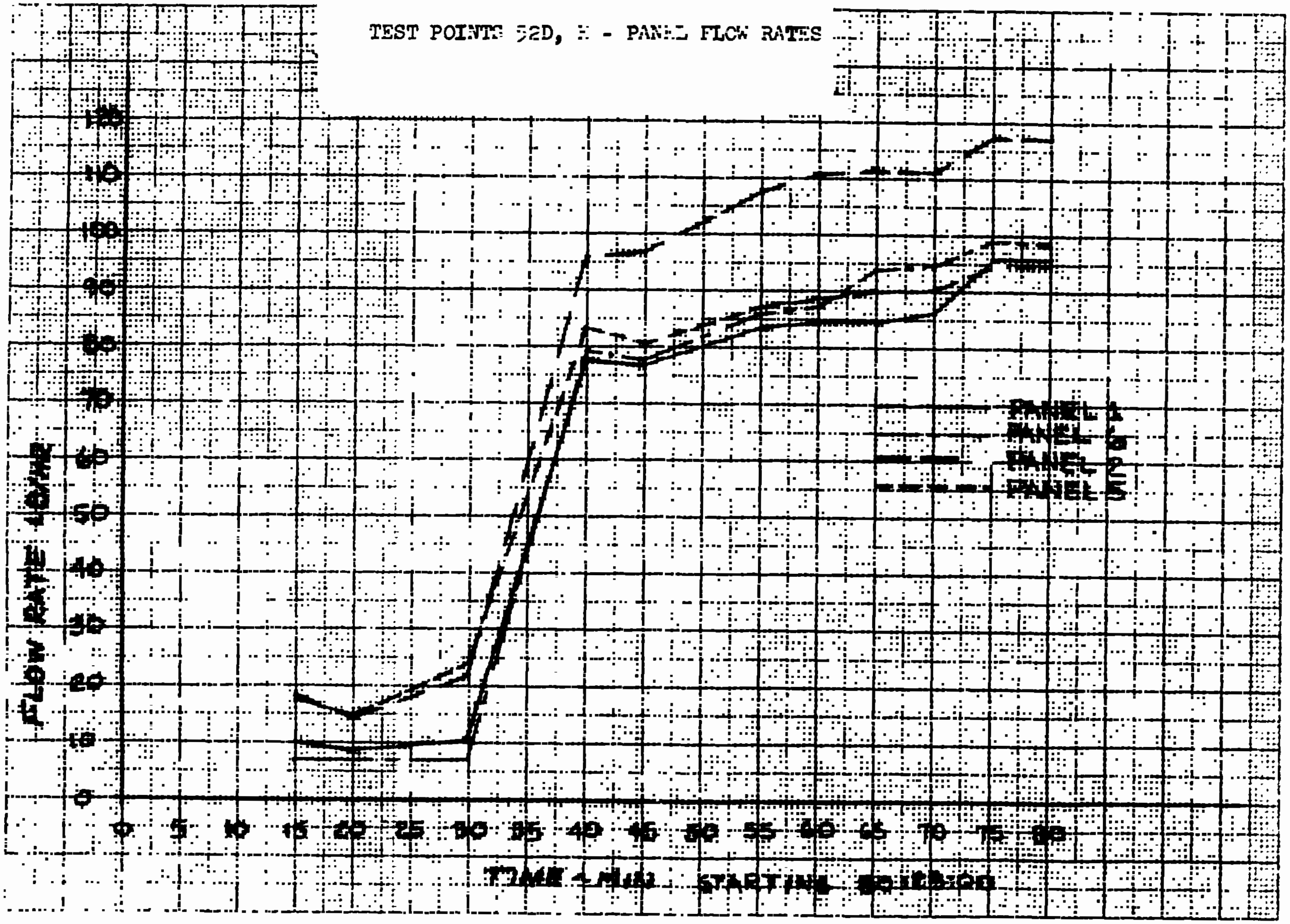


FIGURE 87

TEST POINT 32 - STABILIZED TEMPERATURES

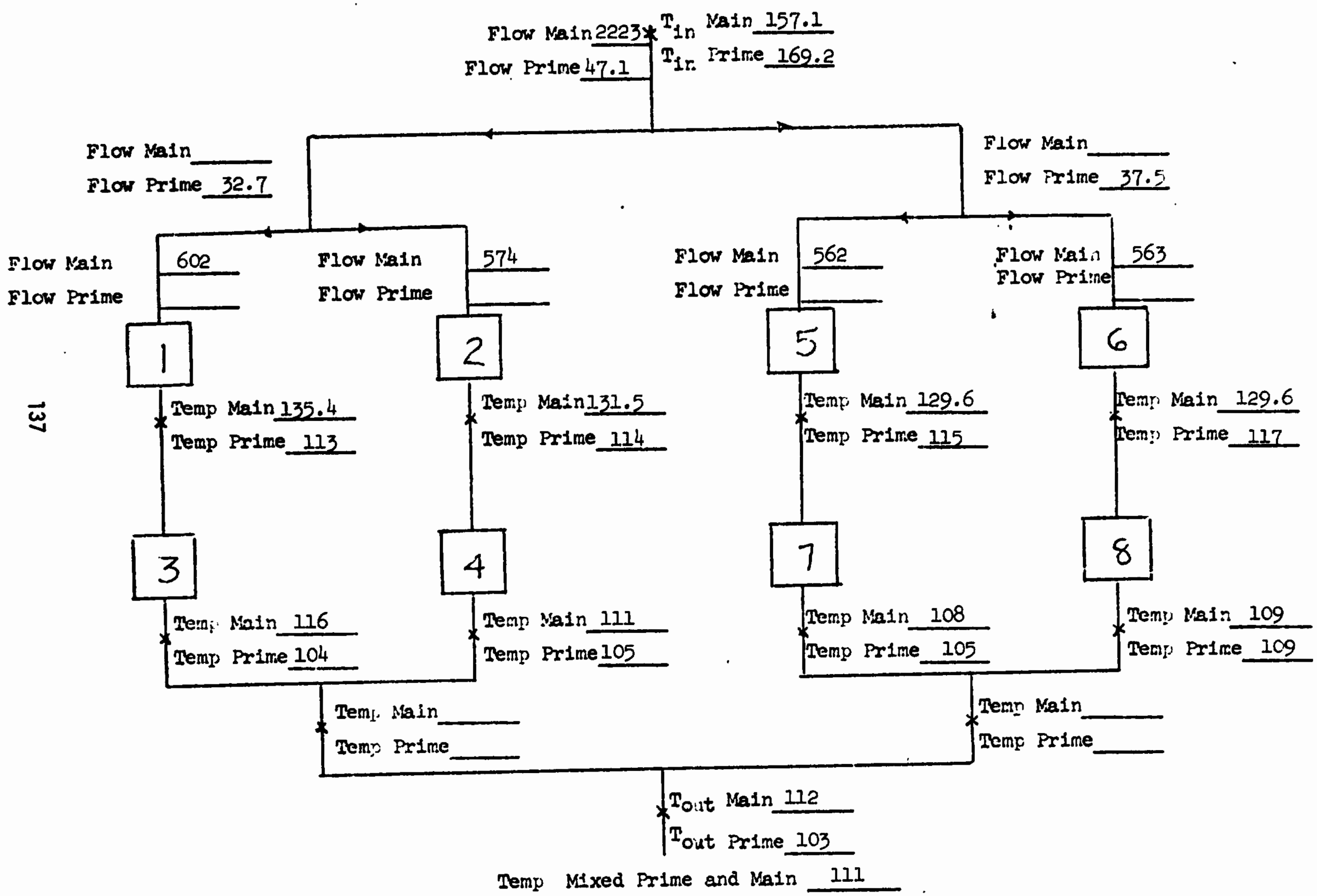


FIGURE 88

TEST POINT 33 - STABILIZED TEMPERATURES

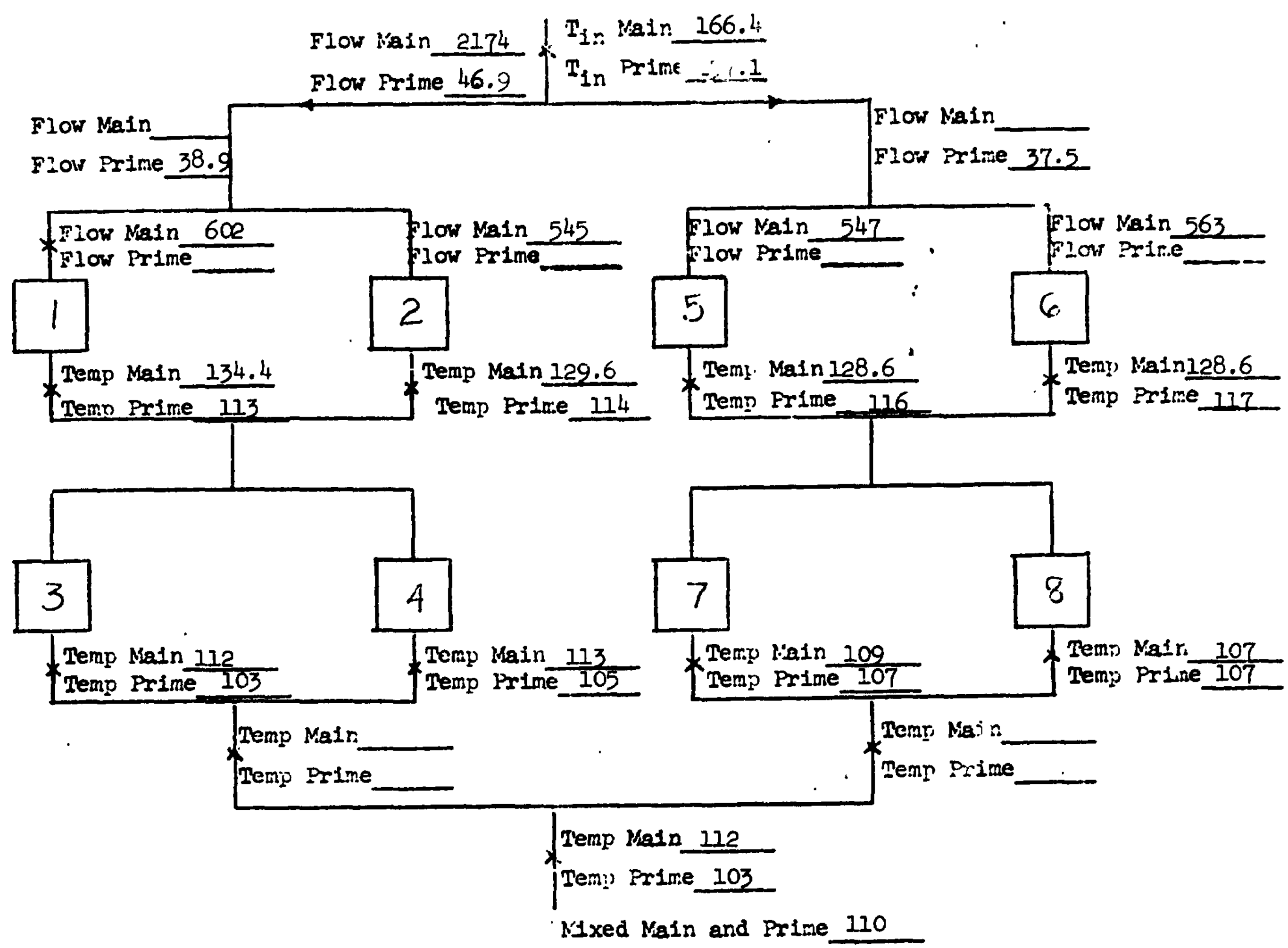


FIGURE 89

TEST POINT 45 - STABILIZED TEMPERATURES

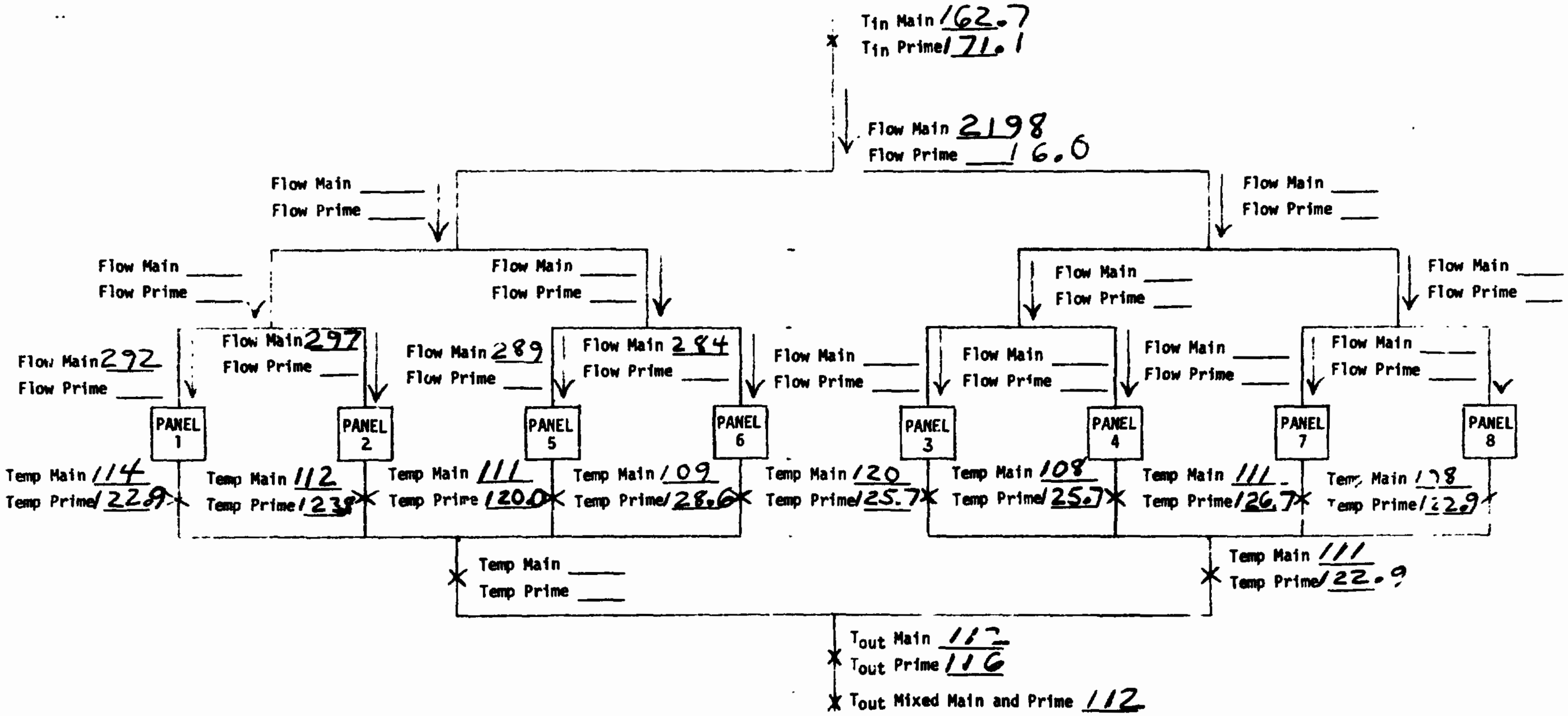


FIGURE 90

TEST POINT 46 - STABILIZED TEMPERATURES

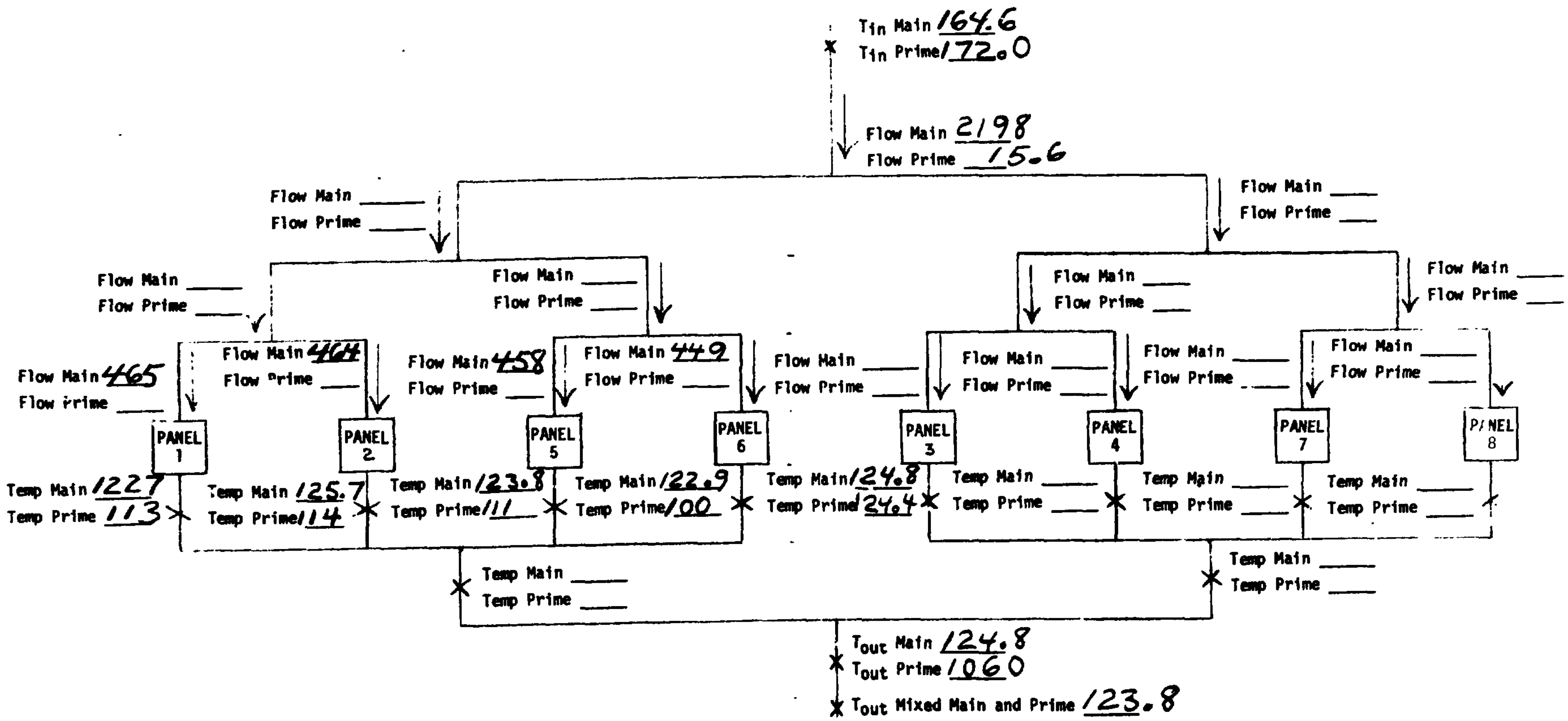


FIGURE 91

TEST POINT 37 - STABILIZED TEMPERATURES

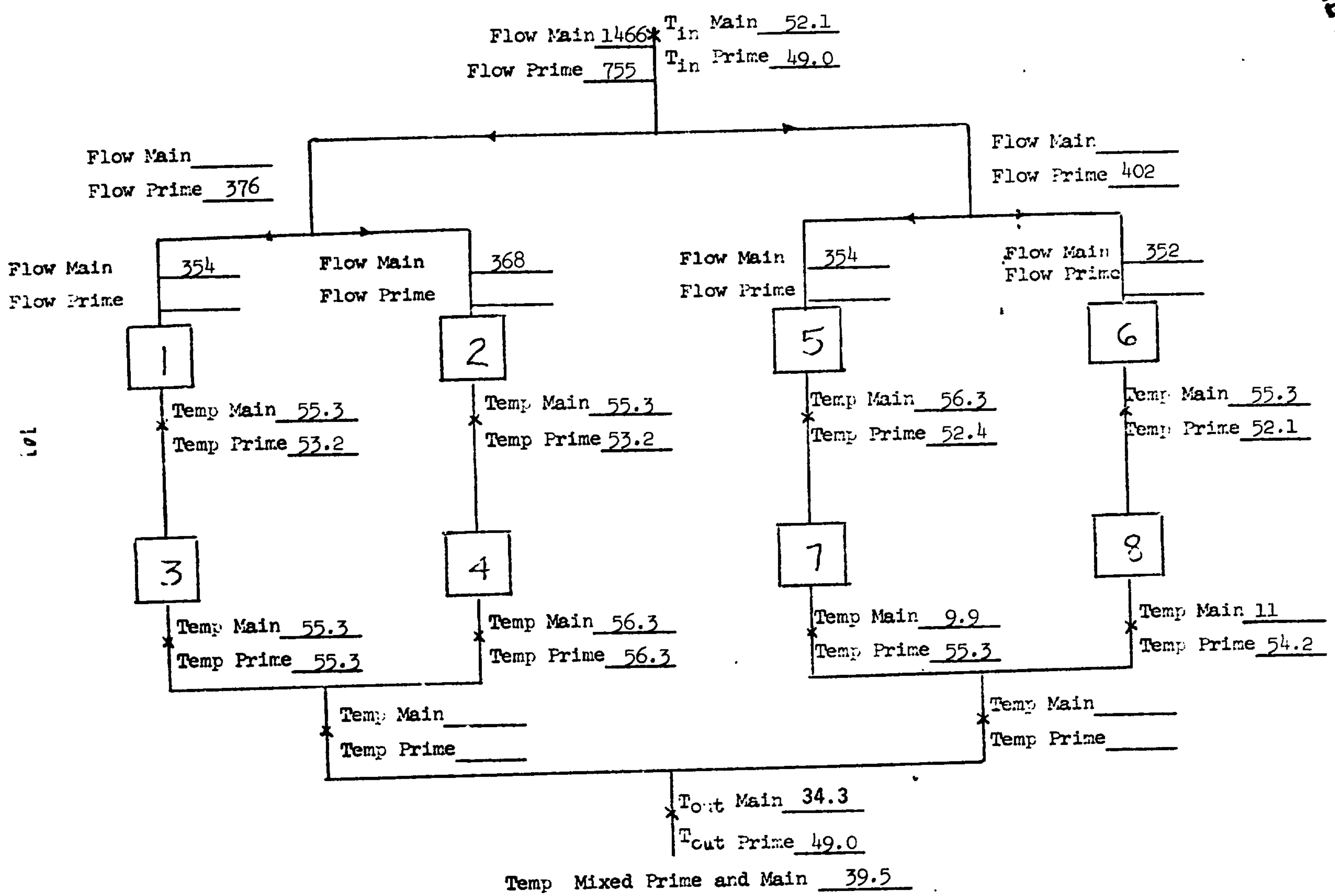


FIGURE 92

TEST POINT 38 - STABILIZED TEMPERATURES

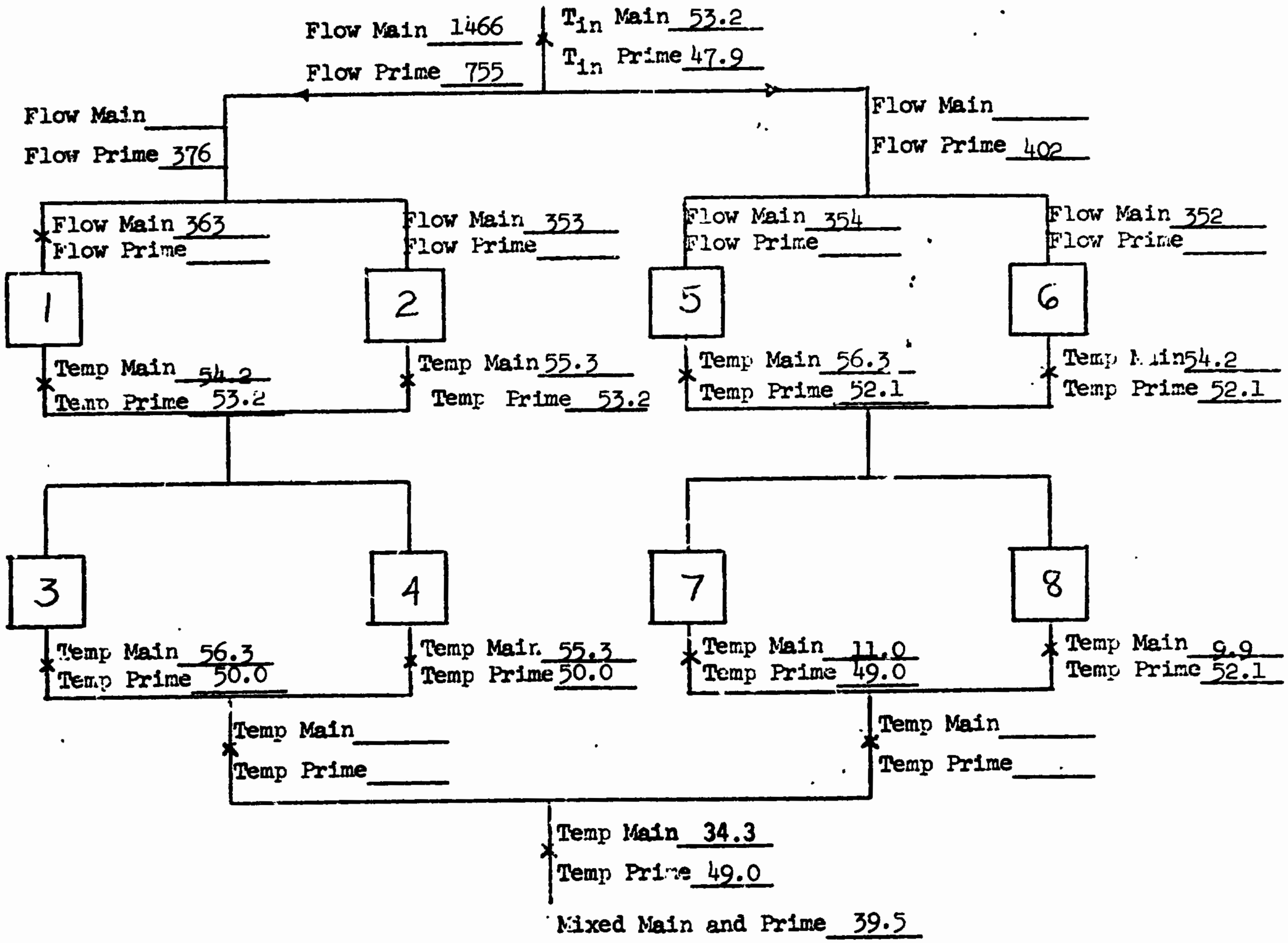


FIGURE 93

TEST POINT 9 - STABILIZED TEMPERATURES

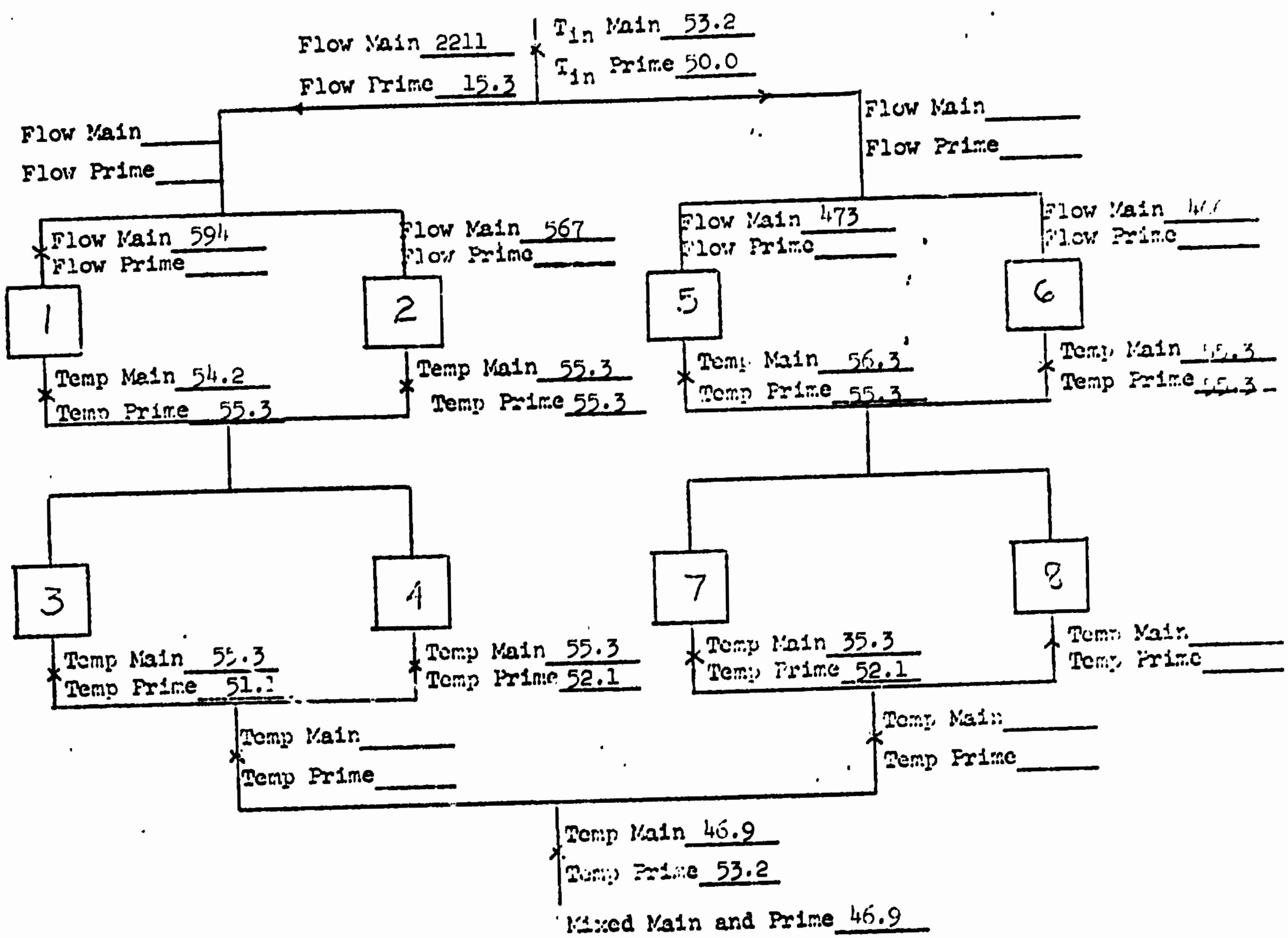


FIGURE 94

TEST POINT 62 - STABILIZED TEMPERATURES

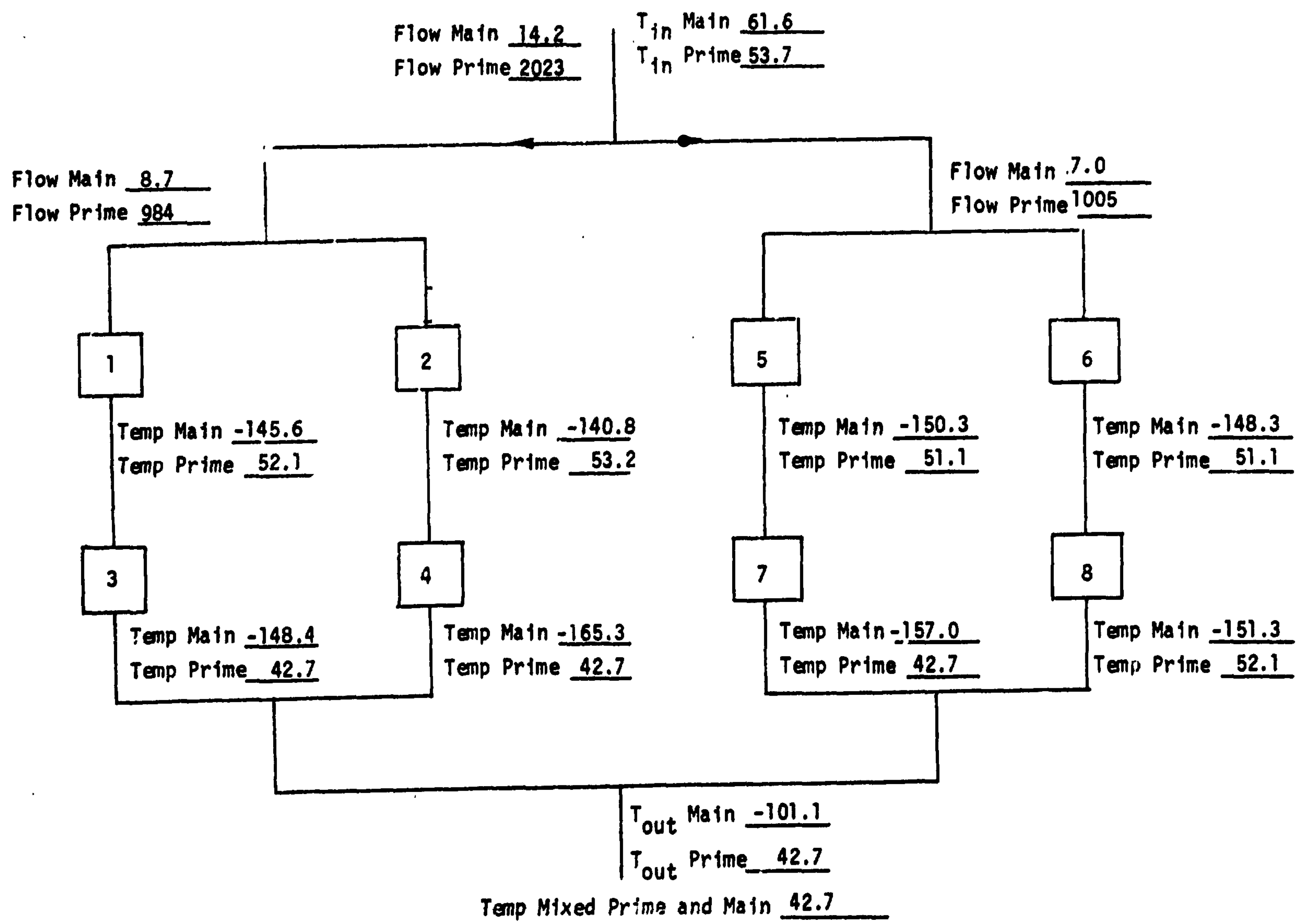


FIGURE 95

TEST POINT 62 TUBE TEMPERATURES AFTER COLD SOAK

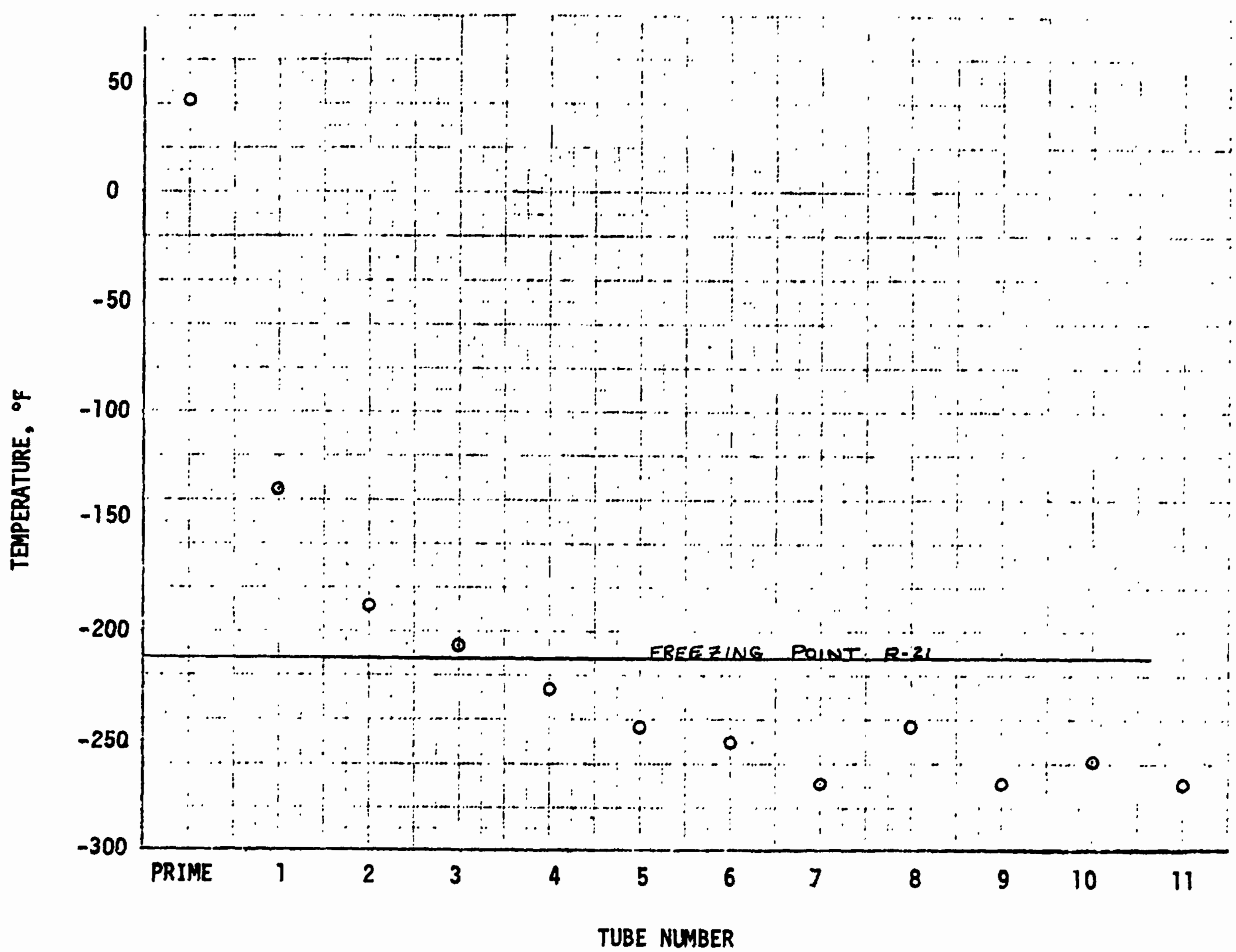


FIGURE 96

TEST POINT 48 - STABILIZED TEMPERA-
TURES

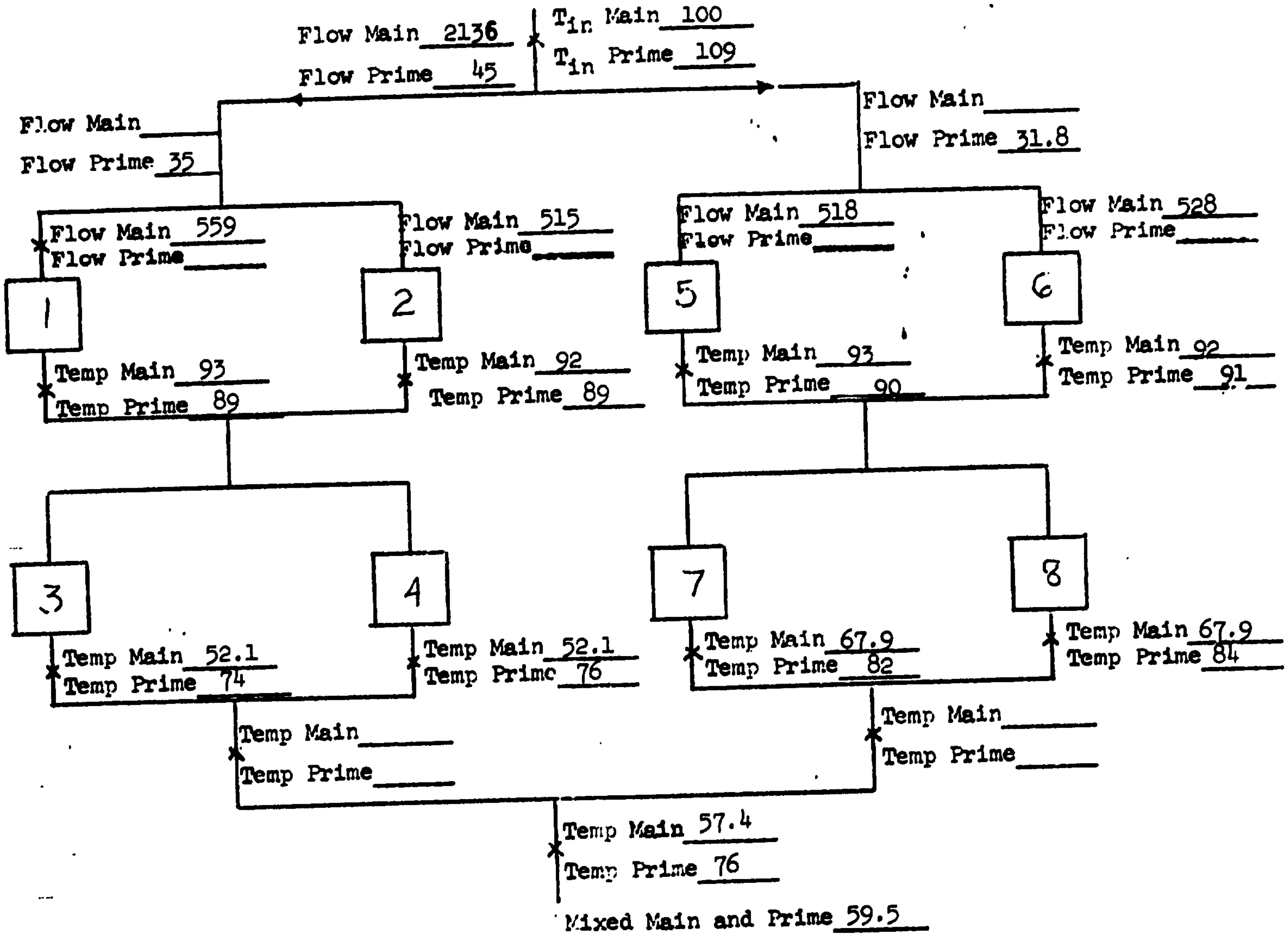


FIGURE 97

TEST POINT 49 - STABILIZED TEMPERATURES

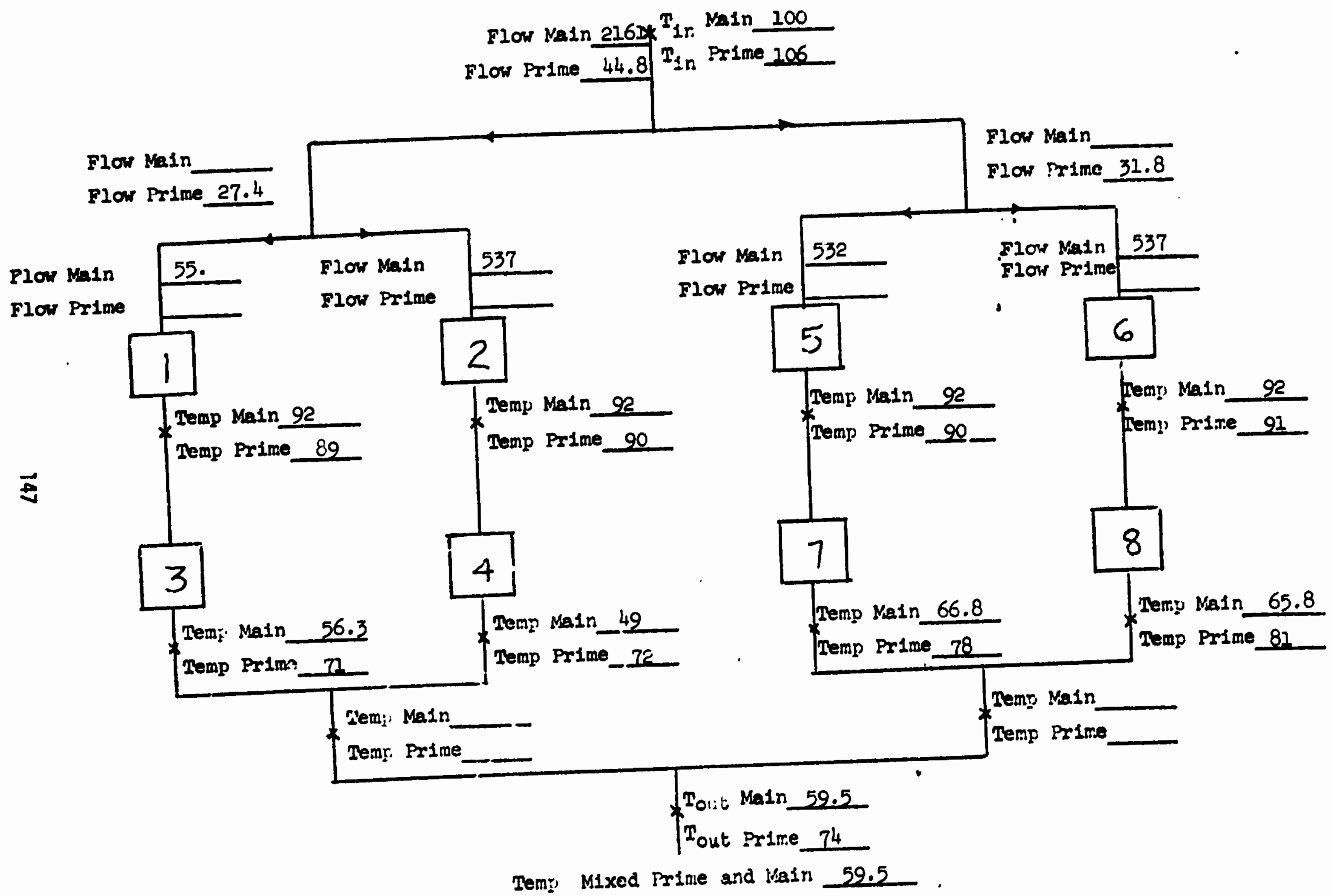


FIGURE 98

TEST POINT 43 - STABILIZED TEMPERATURES

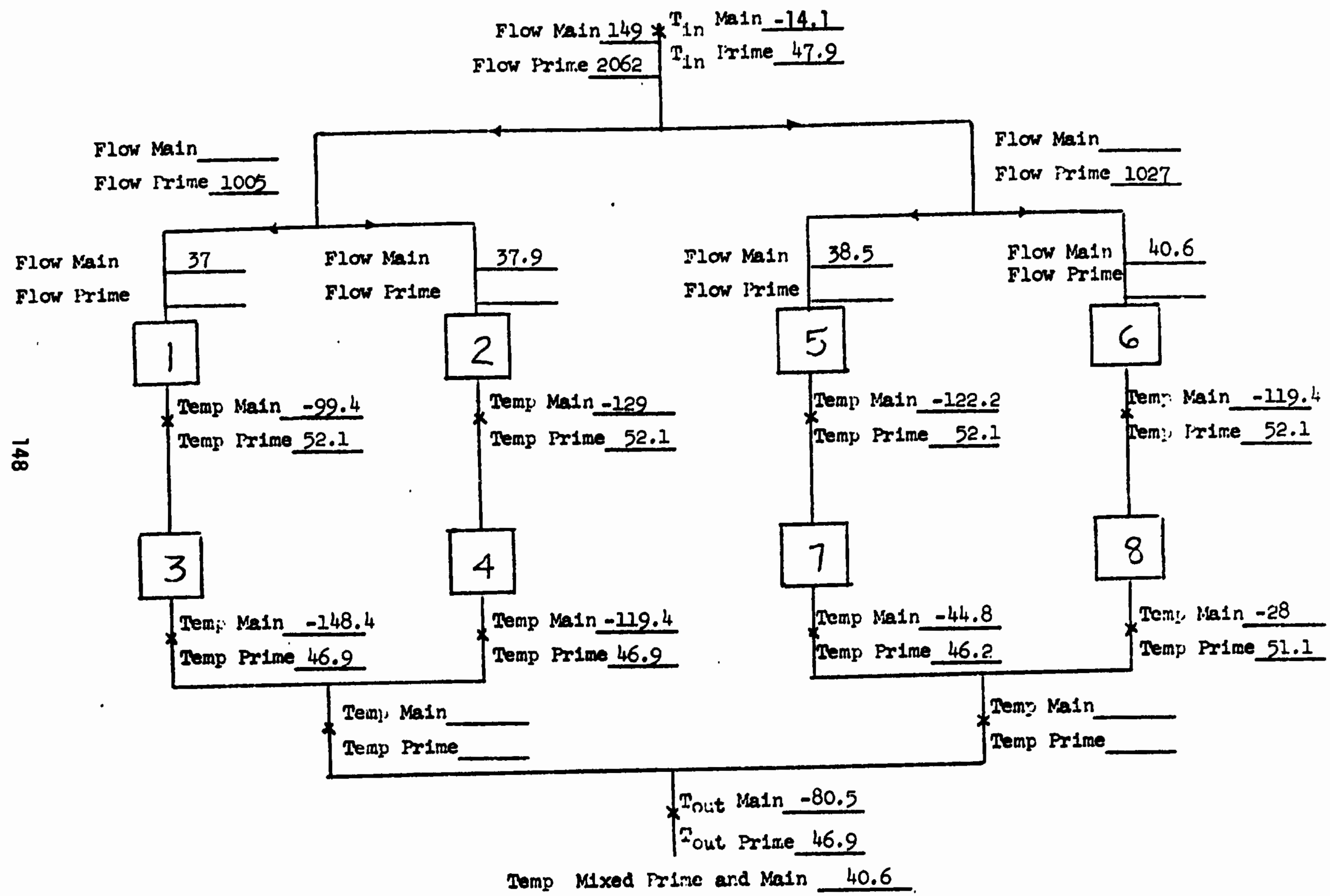


FIGURE 99

COMPARISON OF PLUMBING ARRANGEMENTS

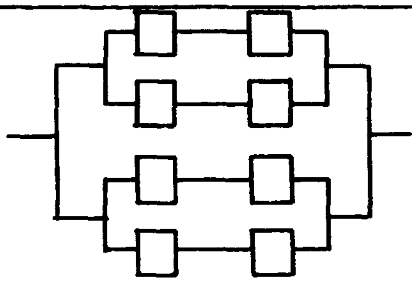
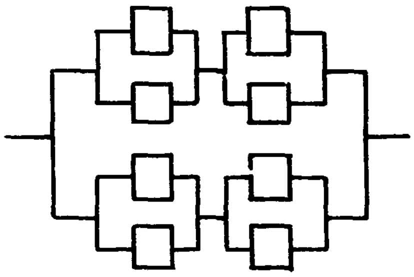
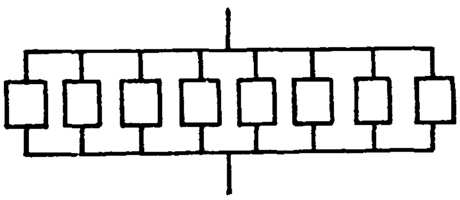
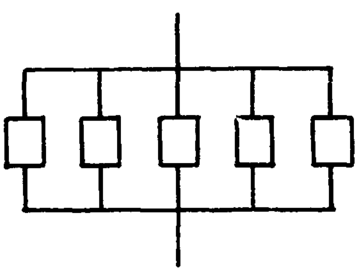
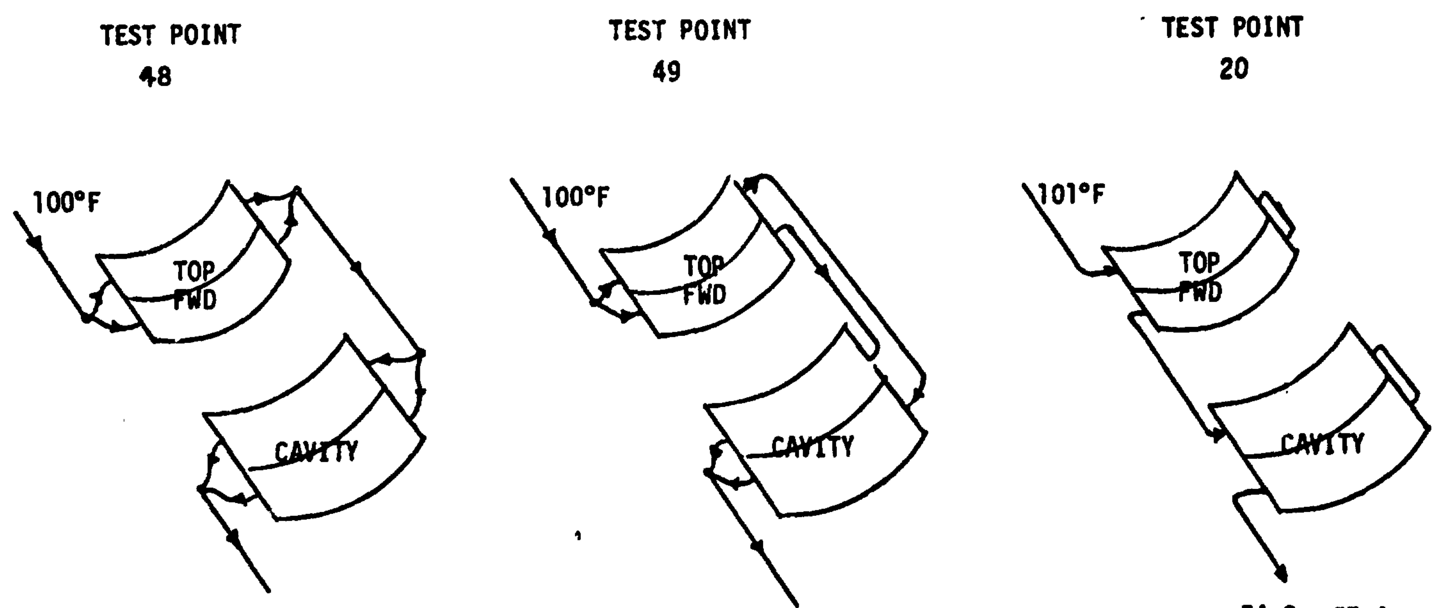
CONFIGURATION	TEST POINT	AVG ENV. BTU/HR FT^2	INLET TEMP °F	OUTLET TEMP °F	HEAT REJECTION BTU/HR	Q/A BTU/HR FT^2
	32	129.8	165.2	111.0	31,909	55.4
	33	129.6	164.1	110.0	30,679	53.4
	45	128.8	161.1	112.	29,408	51.0
	46	129.8	162.7	123.8	22,492	62.5

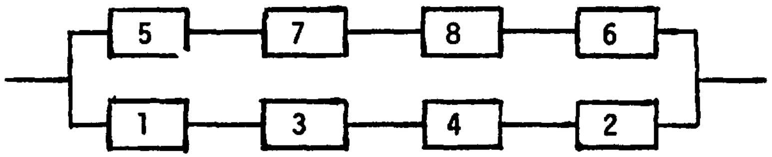
FIGURE 100
COMPARISON OF PLUMBING ARRANGEMENTS



	TEST POINT 48	TEST POINT 49	TEST POINT 20
MAIN OUTLET, °F	59.5	59.5	54.2 - 57.4
TOTAL HEAT REJECTED, BTU/HR	23,258	22,437	24,307-26,165
TOTAL MAIN FLOW, LB/HR	2136	2161	2124-2136
AVG. ENVIRONMENT			
TOP	129.1	128.5	124.3
CAVITY	29.6-81.1 (Steady)	29.5-76.6 (Steady)	35.7-56.4 (Cyclic)

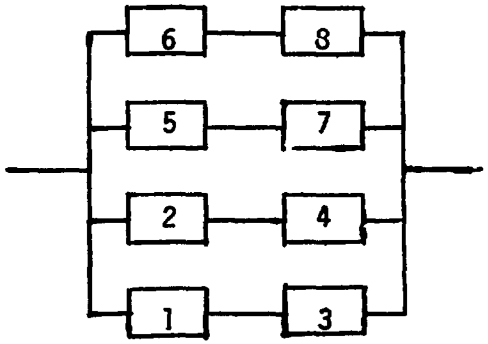
FIGURE 101
COMPARISON OF TEST POINTS 16 AND 43

TEST POINT 16



AVG. ENVIRONMENT, BTU/HR-FT^2	
PANELS	
1, 3, 5, 7	20.1
2 & 4	56 → 29
6 & 8	32.75 → 59
MAIN INLET, °F	-18.7
PRIME INLET, °F	51.6
MAIN OUTLET, °F	-10.6
MIXED OUTLET, °F	44.8
Q_{REJ}, BTU/HR	2190

TEST POINT 43



AVG. ENVIRONMENT, BTU/HR-FT^2	
PANELS	
1, 2, 5, 6	8.35
3 & 4	10.1
7 & 8	51.4
MAIN INLET, °F	-14.2
PRIME INLET, °F	53.2
MAIN OUTLET, °F	-80.5
MIXED OUTLET, °F	40.6
Q_{REJ}, BTU/HR	5487

FIGURE 102

COLDEST TUBE TEMPERATURES AT START OF
HEAT LOAD TRANSIENT - TEST POINT 47

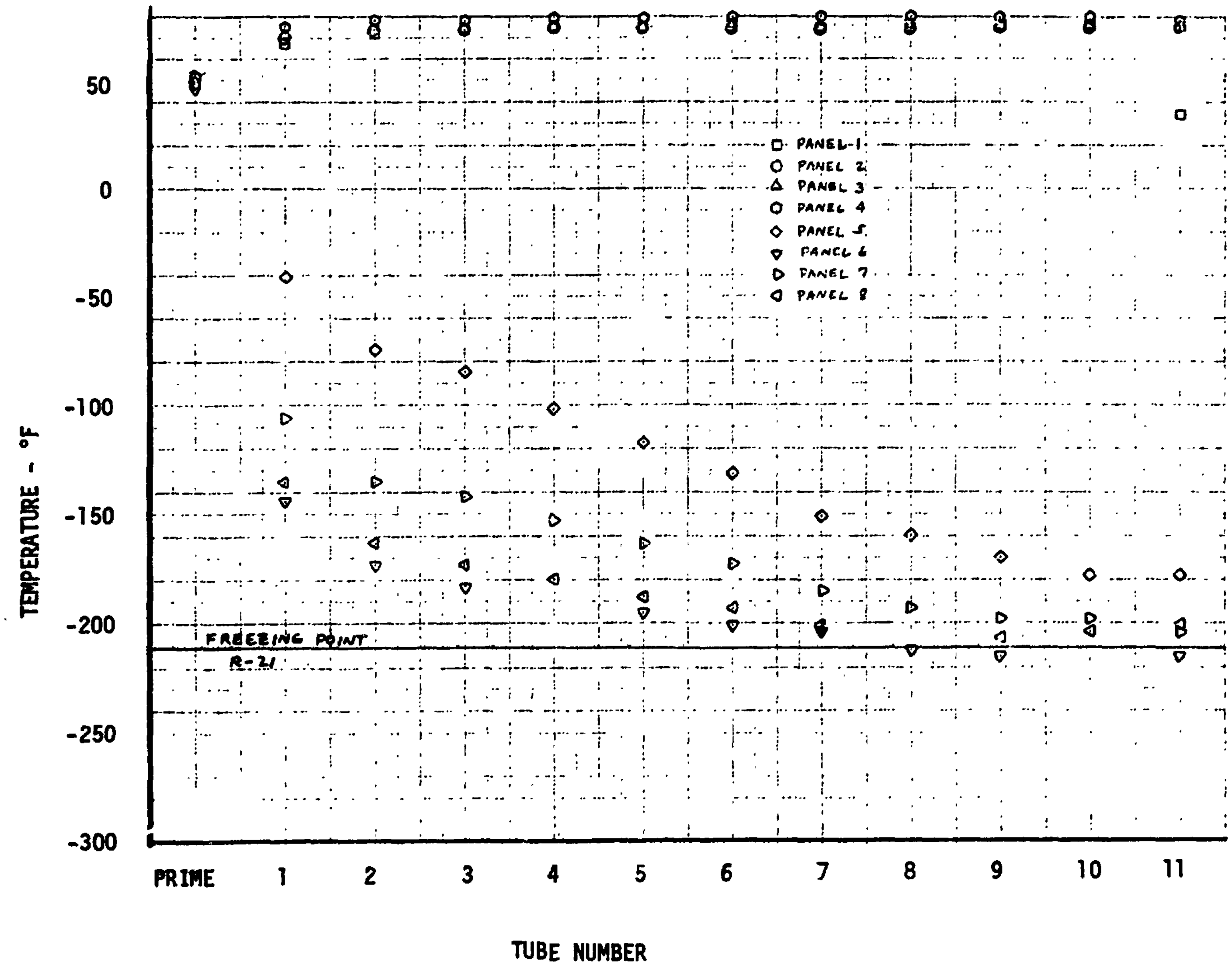


FIGURE 103

COLDEST TUBE TEMPERATURES AT START OF
HEAT LOAD TRANSIENT - TEST POINT 19

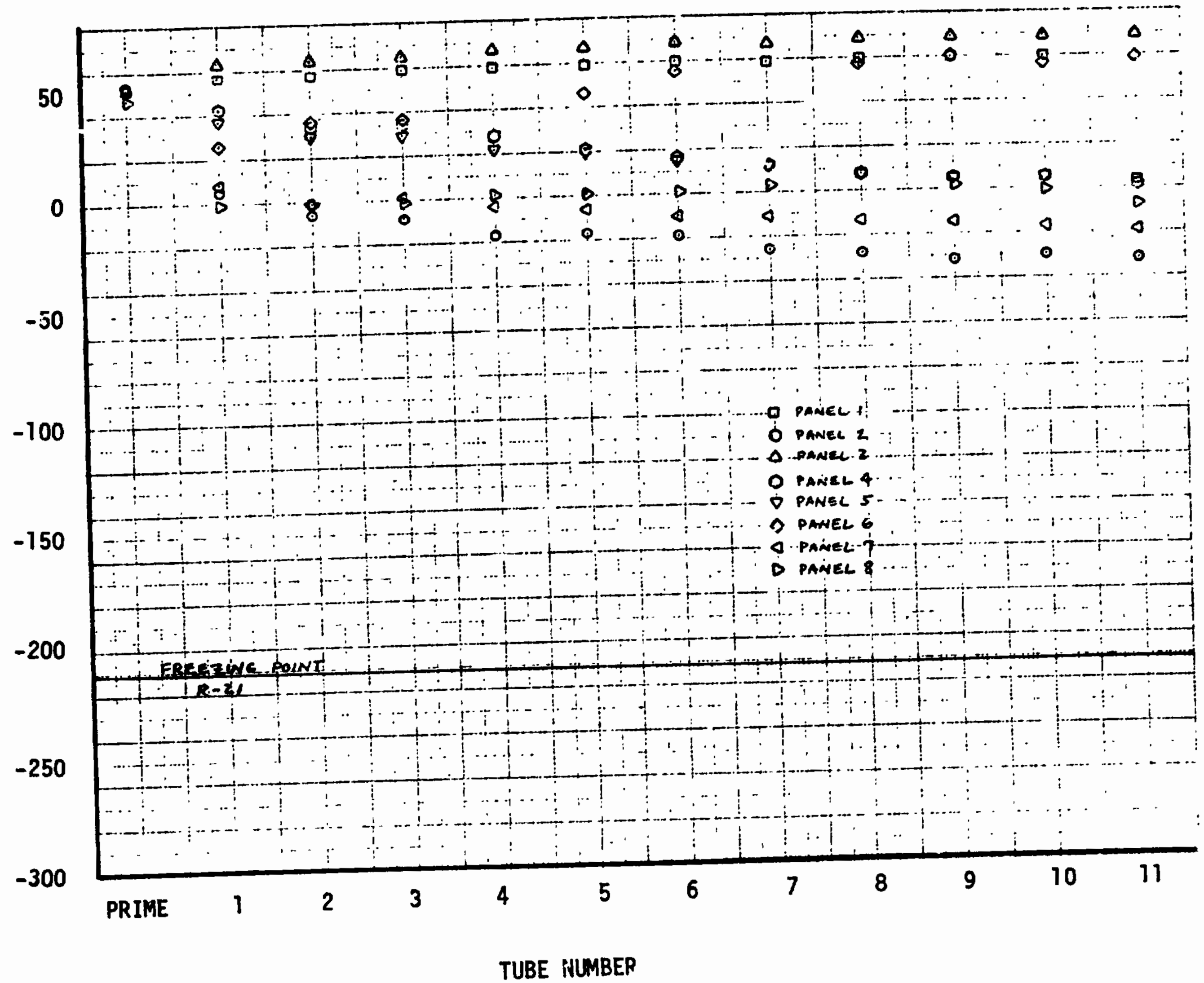


FIGURE 104

COLDEST TUBE TEMPERATURES AT START OF HEAT LOAD TRANSIENT - TEST POINT 50

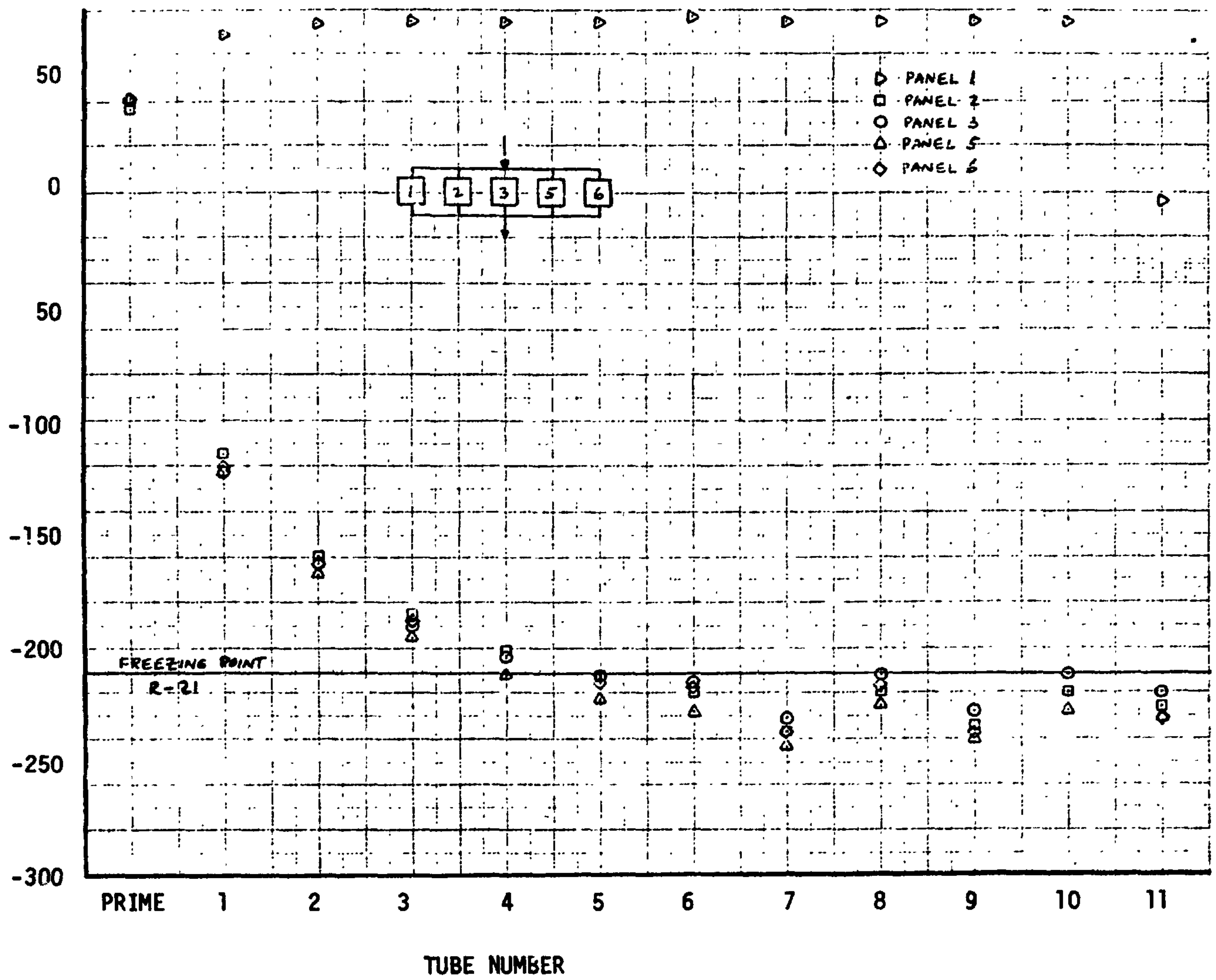


FIGURE 105

COLDEST TUBE TEMPERATURES AT START OF
HEAT LOAD TRANSIENT - TEST POINT 17A-18

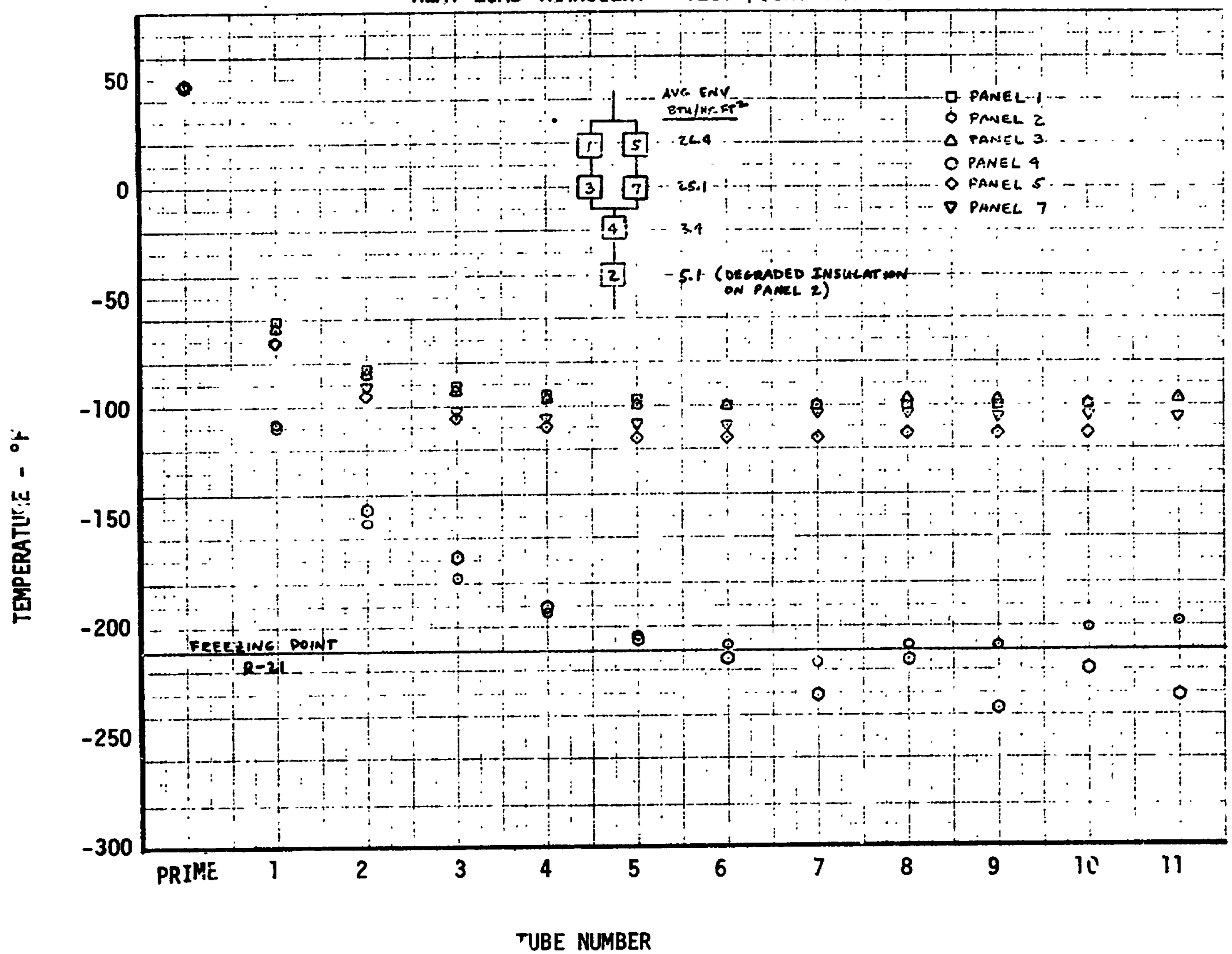


FIGURE 106

COLDEST TUBE TEMPERATURES AT START OF
HEAT LOAD TRANSIENT - TEST POINT 36-36A

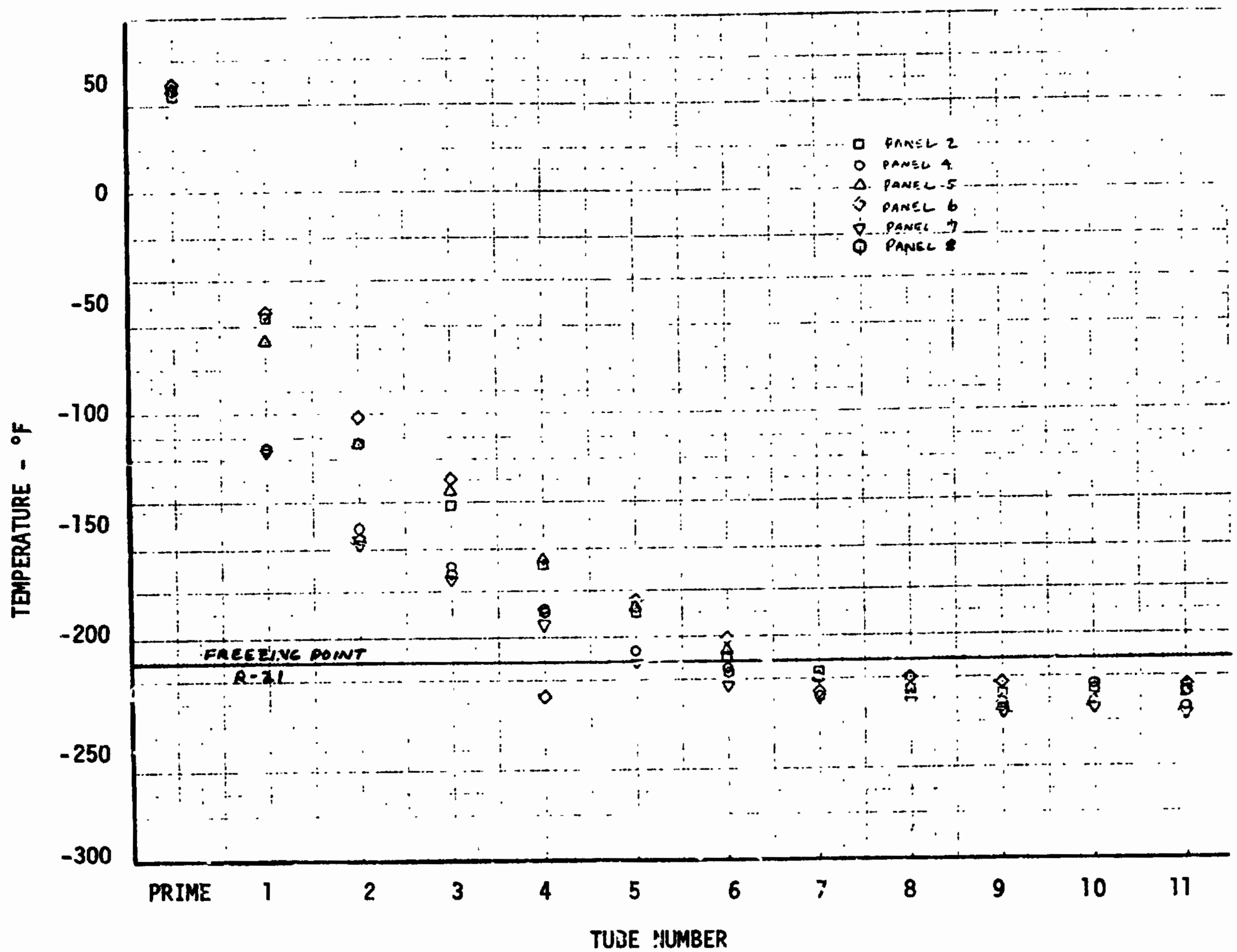


FIGURE 107

COLDEST TUBE TEMPERATURE AT START OF
HEAT LOAD TRANSIENT - TEST POINT 60

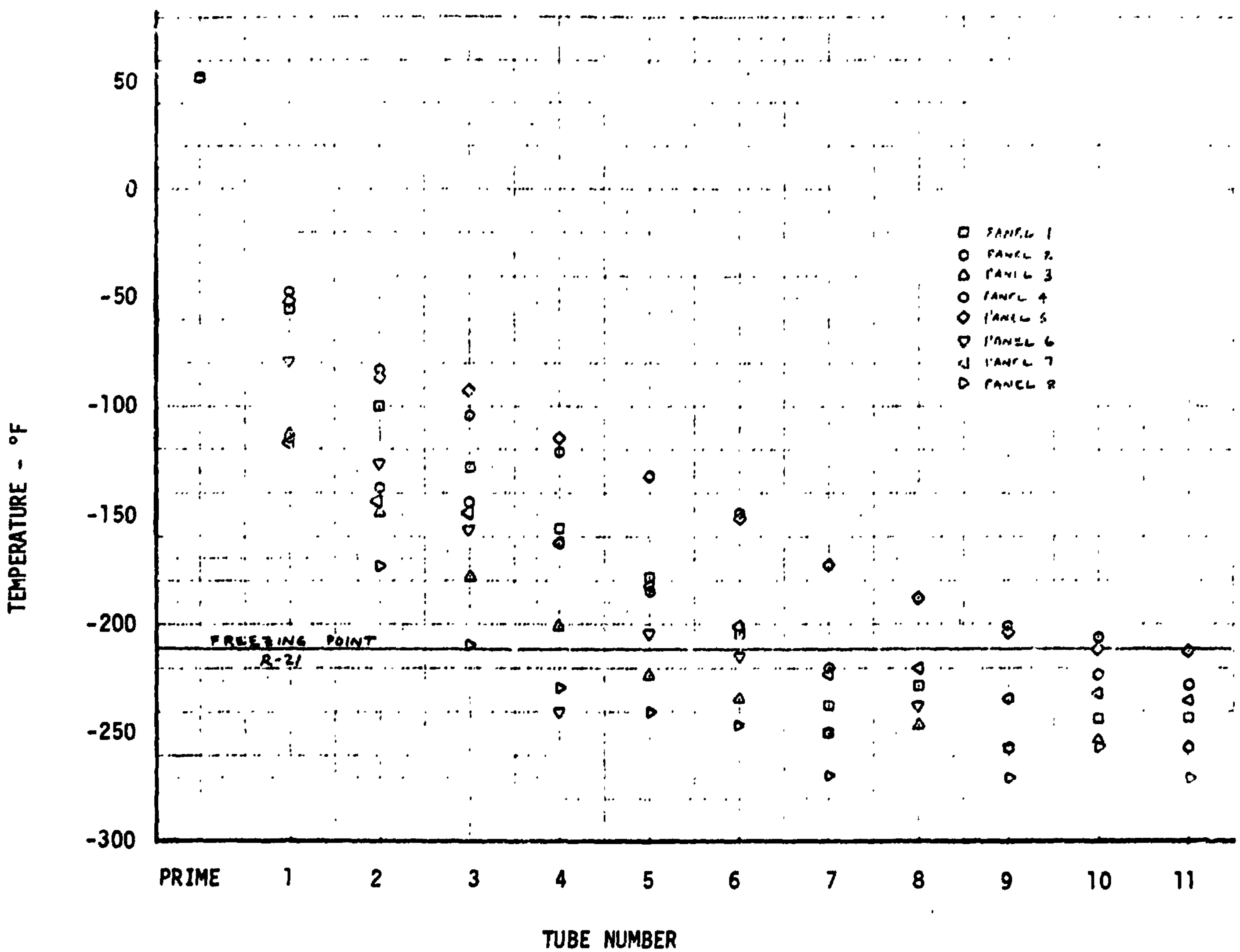


FIGURE 108

TEST POINT 47 - TOTAL, PRIME, BANK FLOWRATES

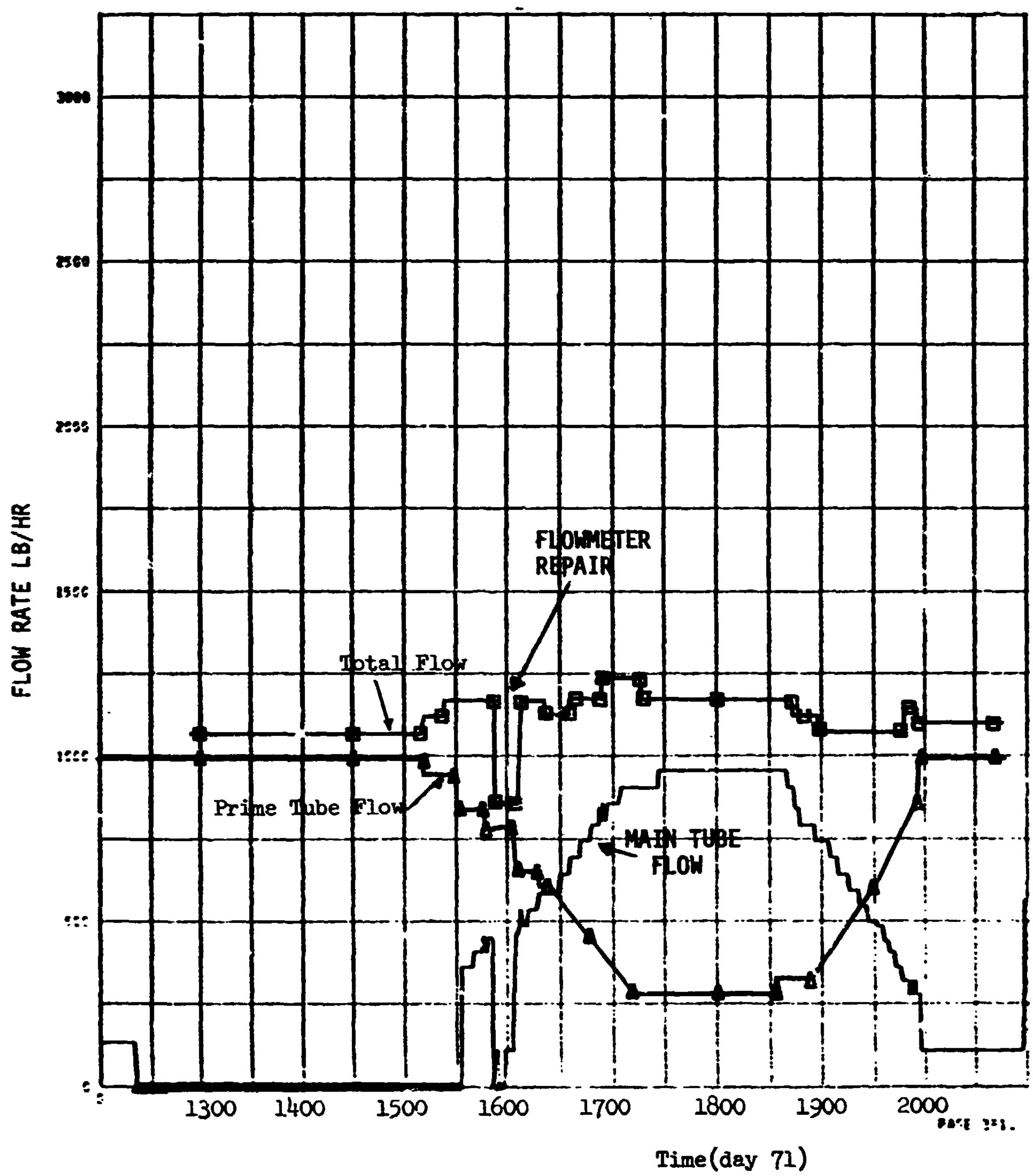


FIGURE 109

TEST POINT 47 - LEG FLOWRATES DURING TRANSIENT

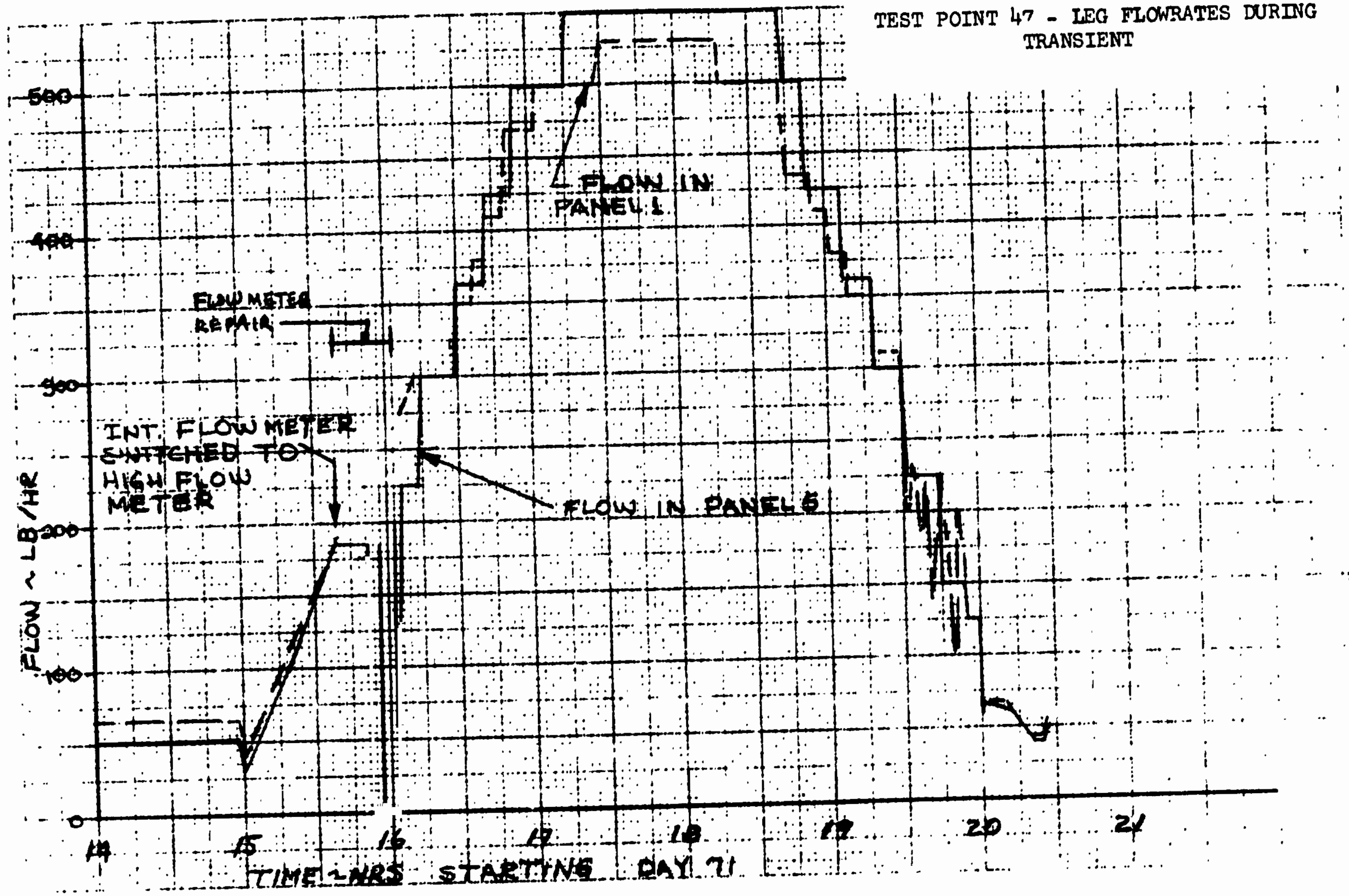


FIGURE 110

TEST POINT 47 - BANK AND PRIME INLET AND OUTLET TEMPERATURES, MIXED OUTLET TEMPERATURE

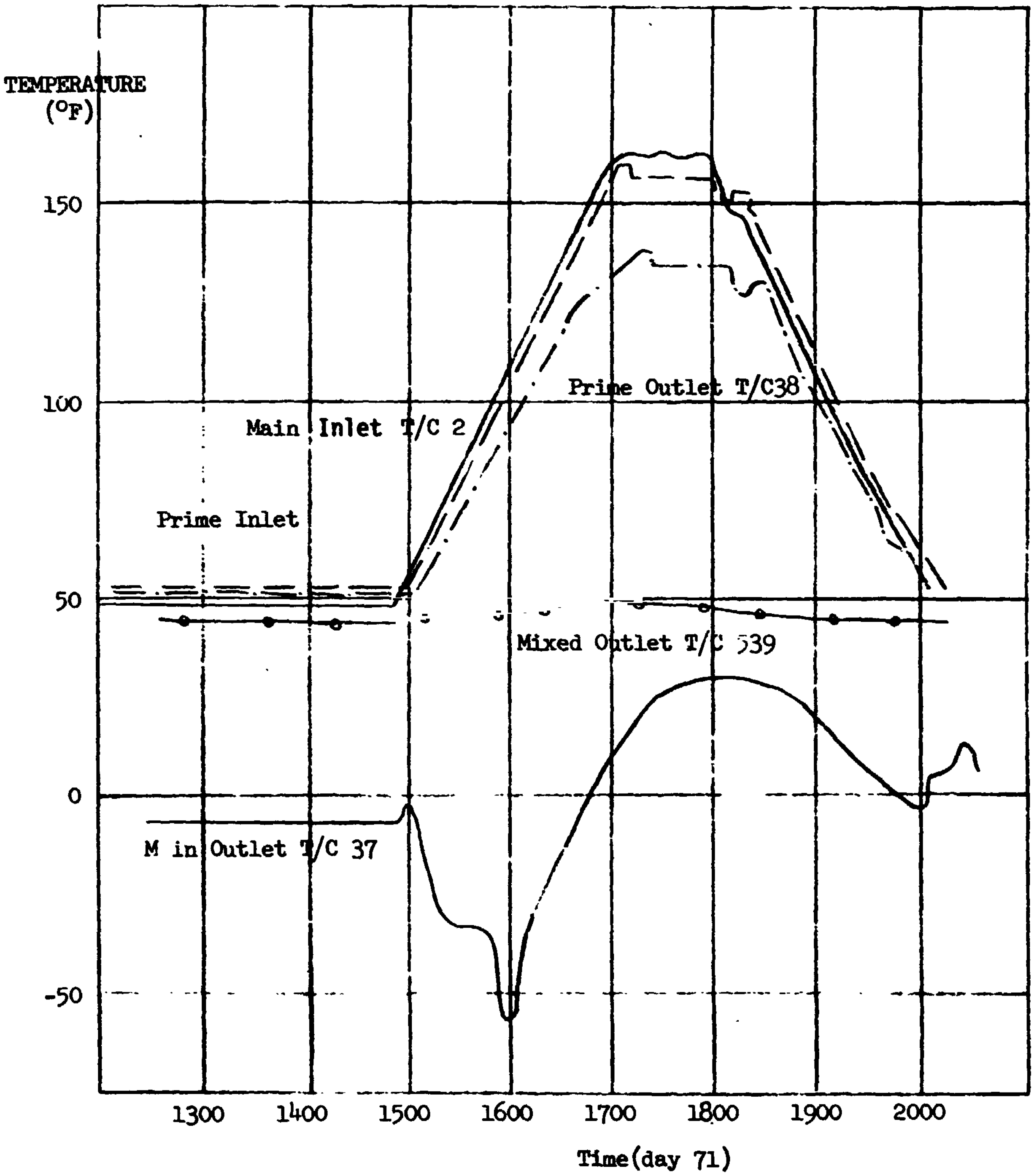


FIGURE 111

TEST POINT 47 - OUTLET TEMPERATURES OF PANELS 1, 2, 3, 4

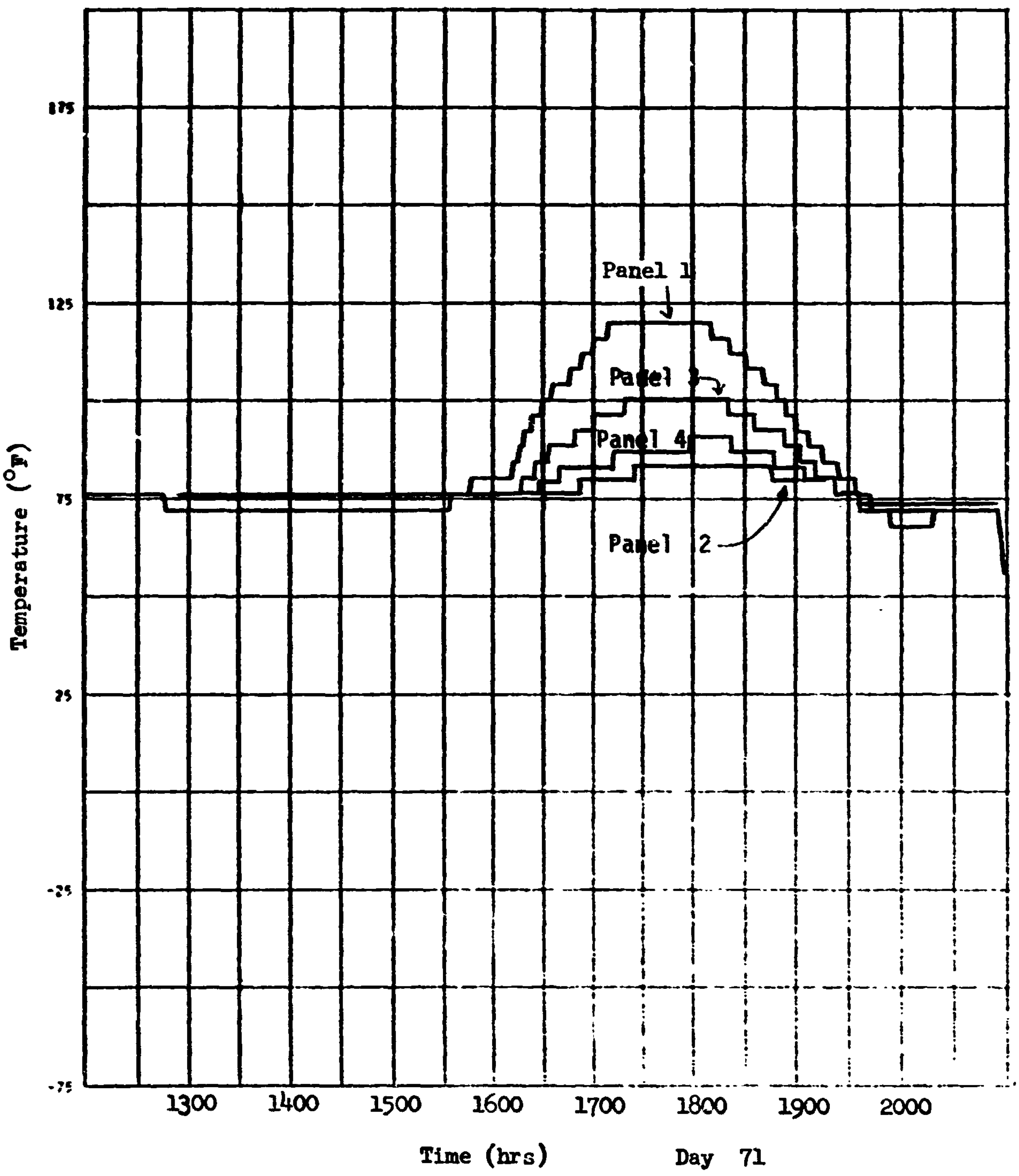


FIGURE 112

TEST POINT 47 - OUTLET TEMPERATURE OF
PANELS 5, 6, 7, 8

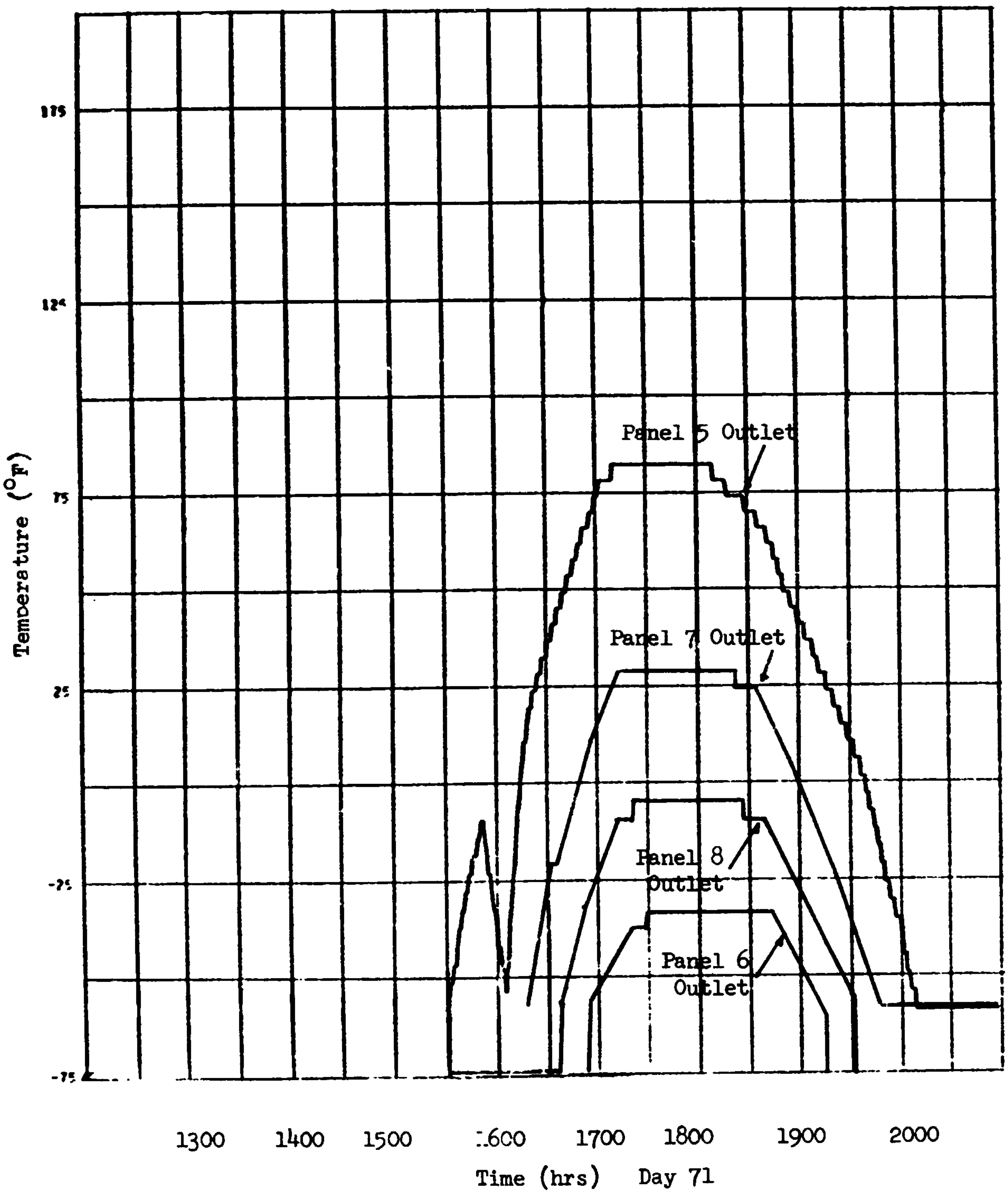


FIGURE 113

TEST POINT 19 - TOTAL, BANK, PRIME FLOWRATES

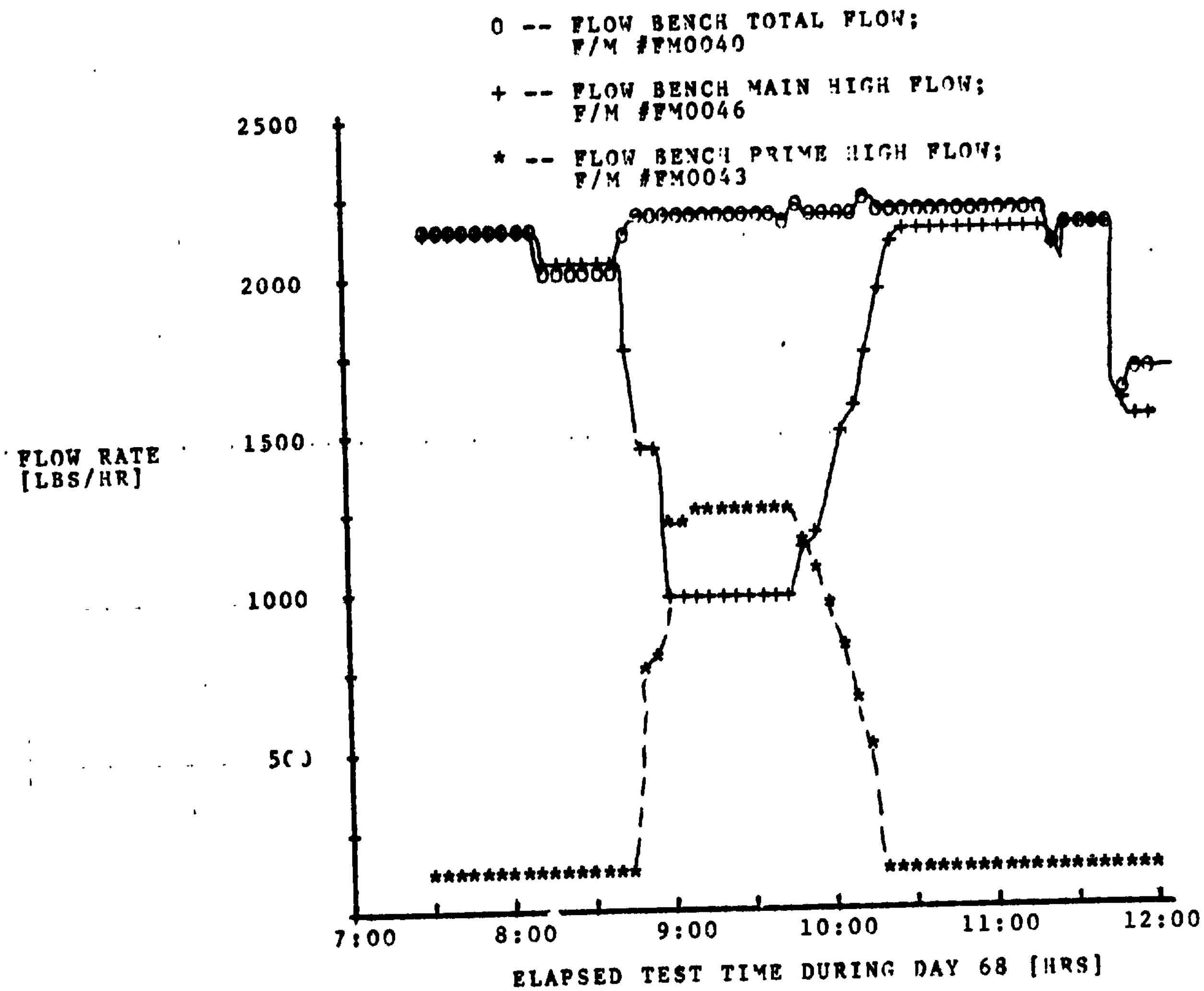


FIGURE 114

TEST POINT 19 - BANK FLOWRATES

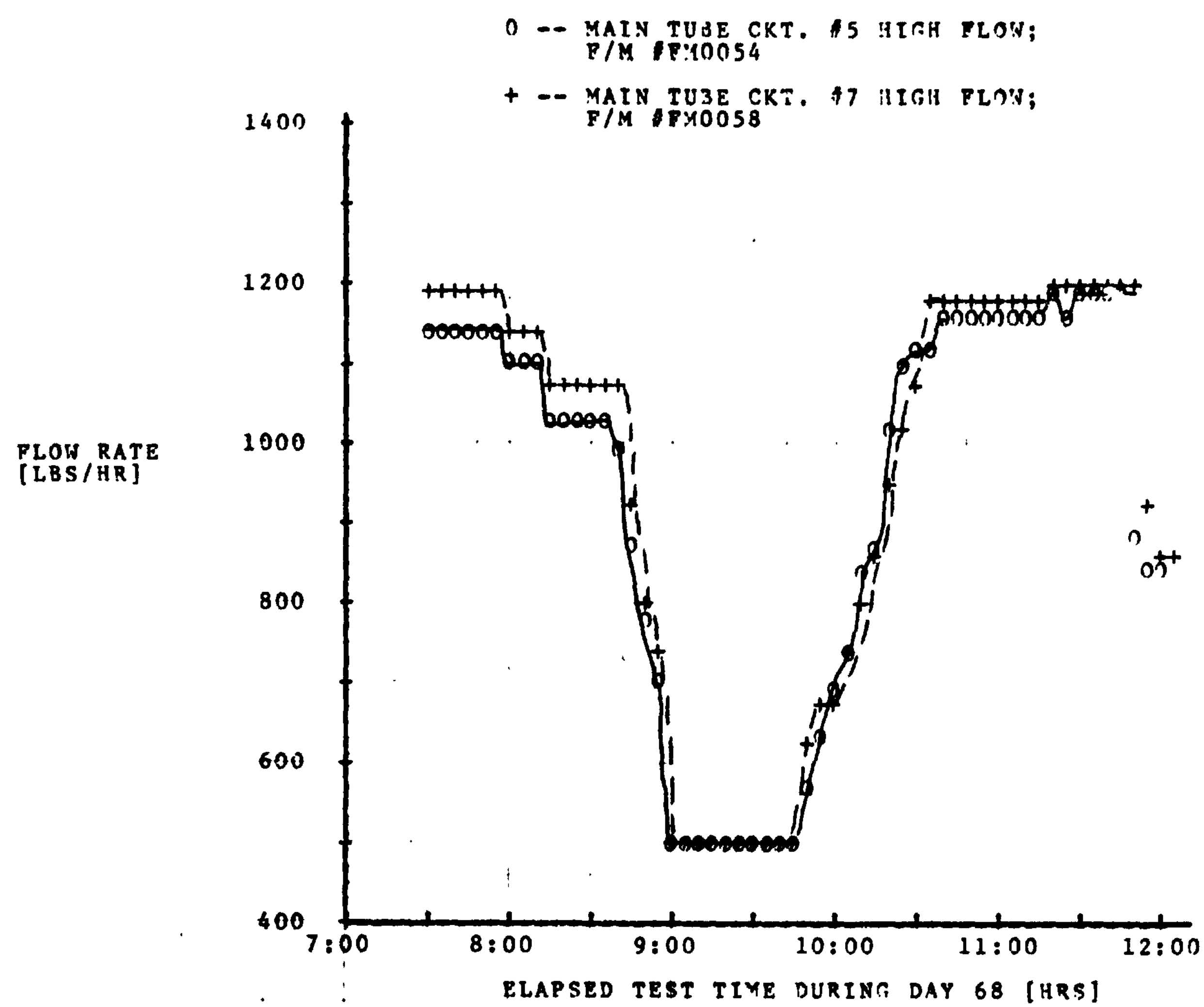


FIGURE 115

TEST POINT 19 - PRIME FLOWRATES

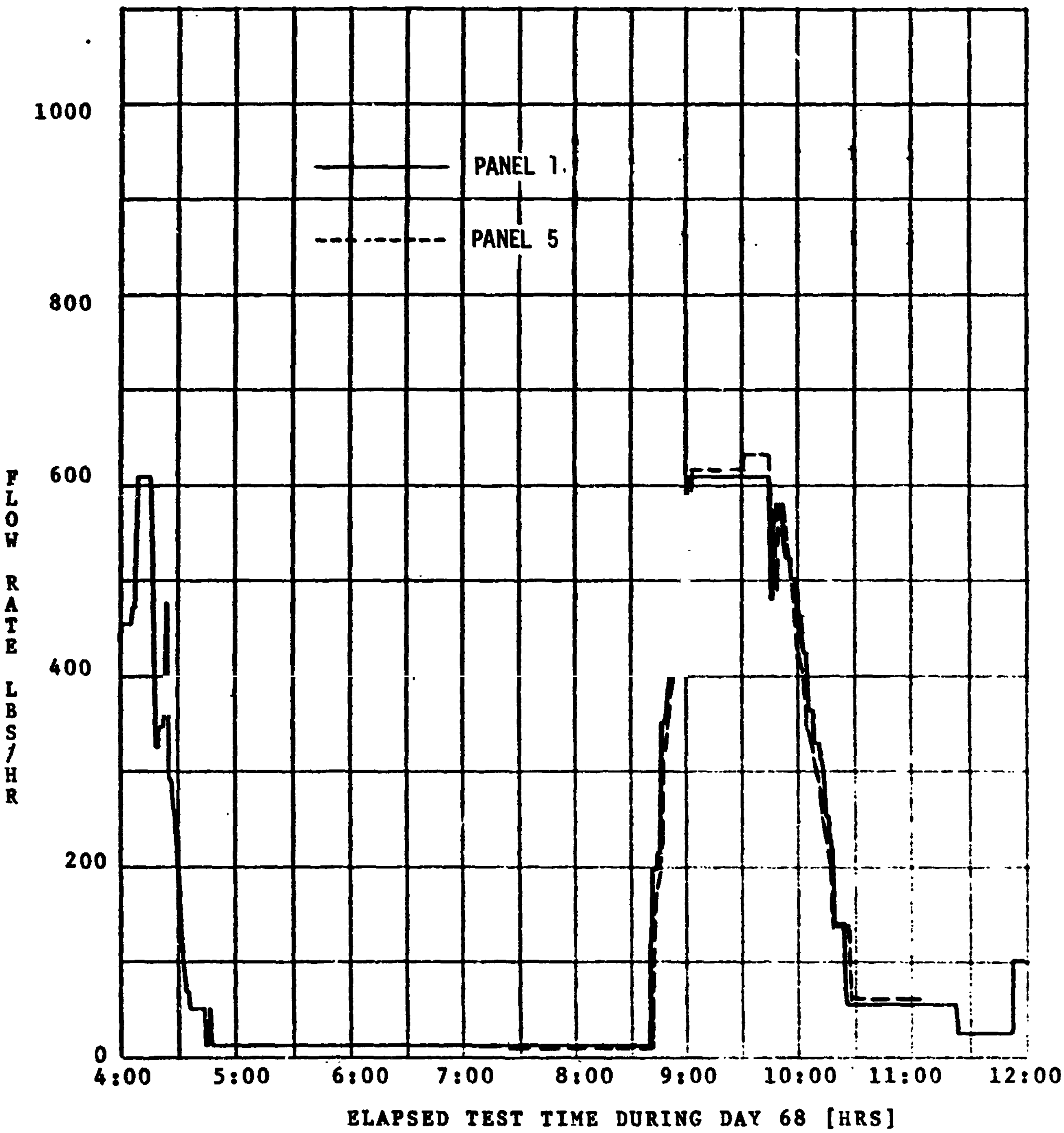


FIGURE 116

TEST POINT 19 - BANK INLET AND OUTLET TEMPS, PANELS 2, 6 OUTLET TEMPS

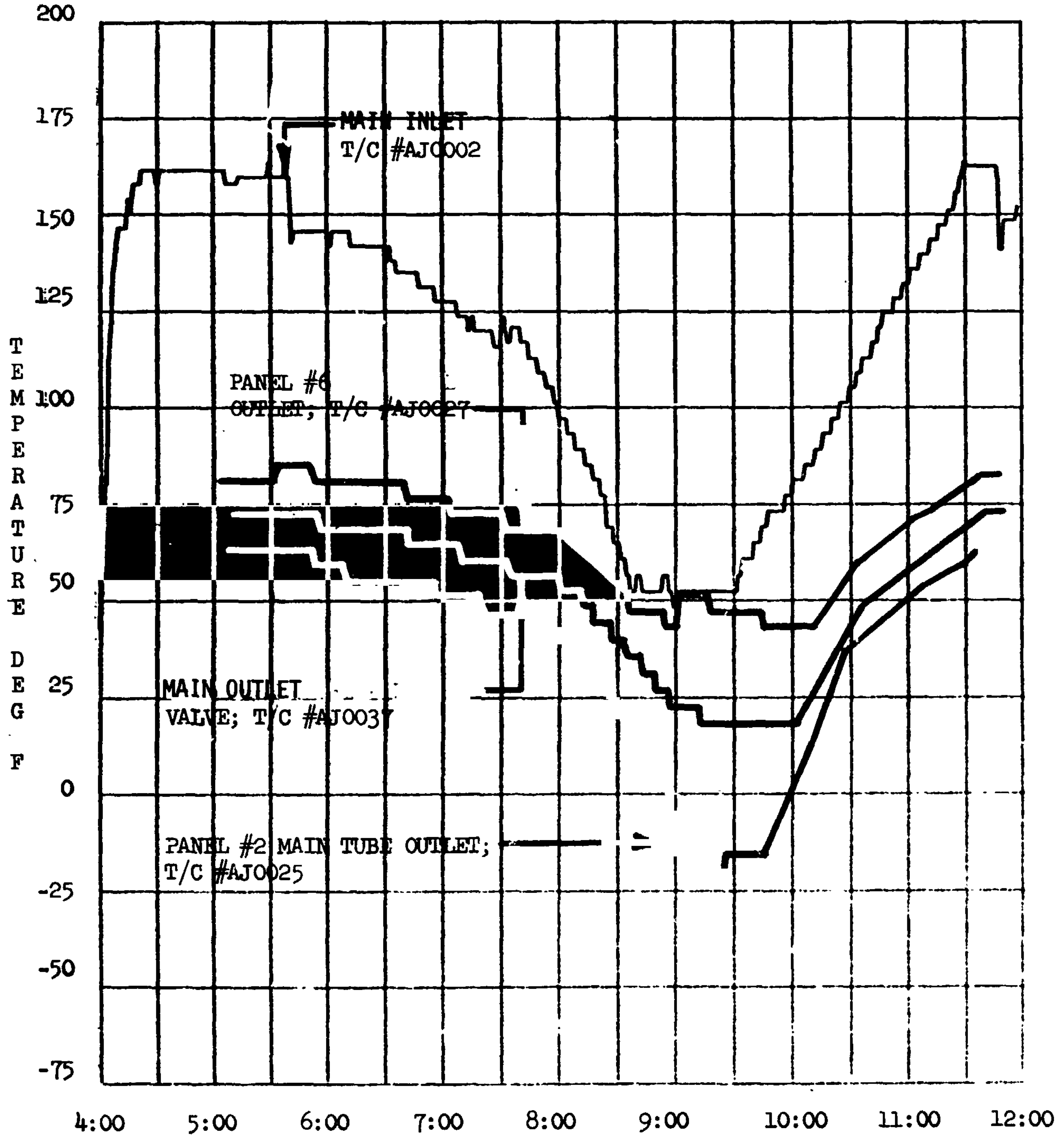


FIGURE 117

TEST POINT 19 - PANELS 1, 2, 3, 4
BANK OUTLET TEMPERATURES

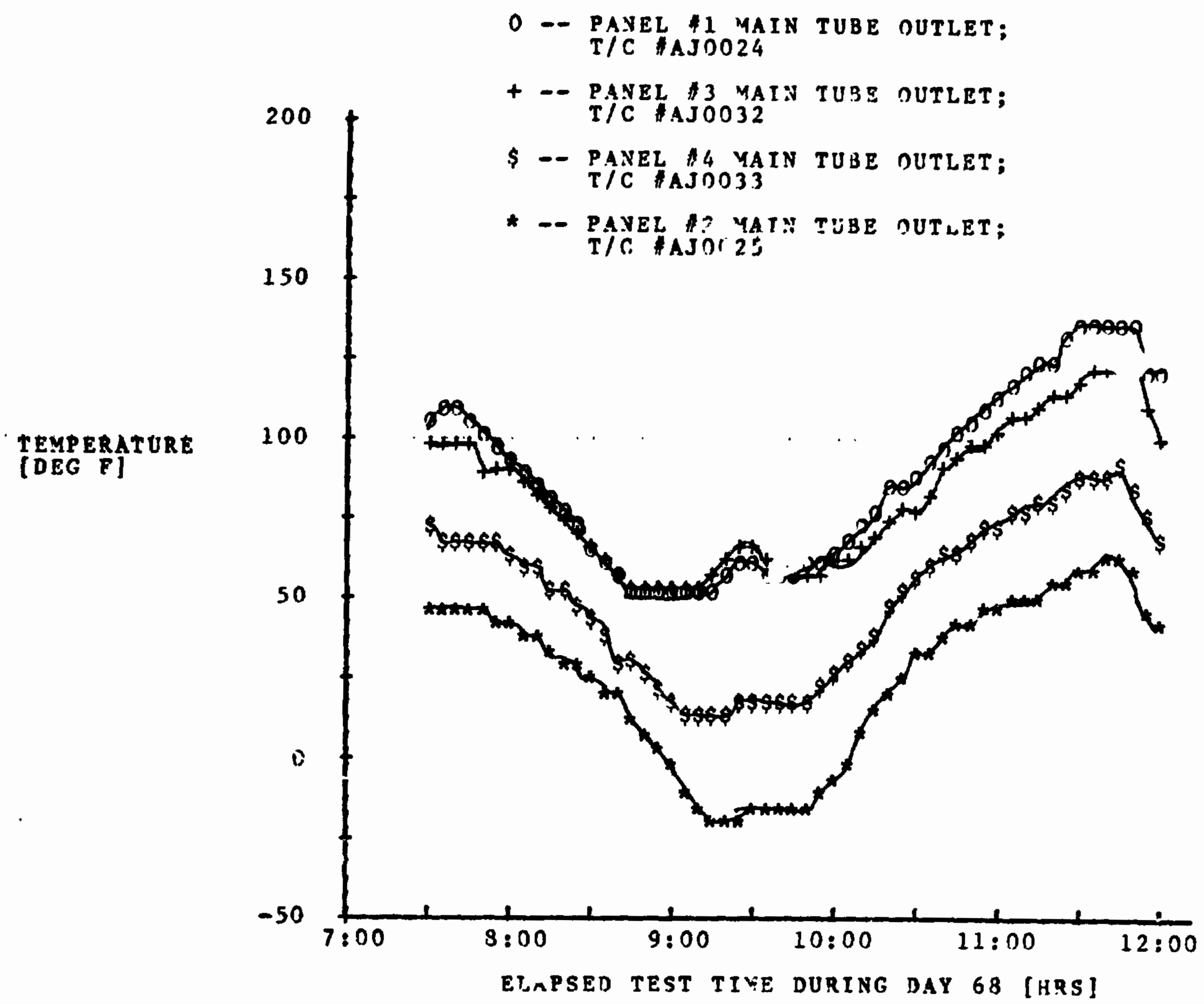


FIGURE 118

TEST POINT 19 - PANELS 5, 6, 7, 8 BANK
OUTLET TEMPERATURES

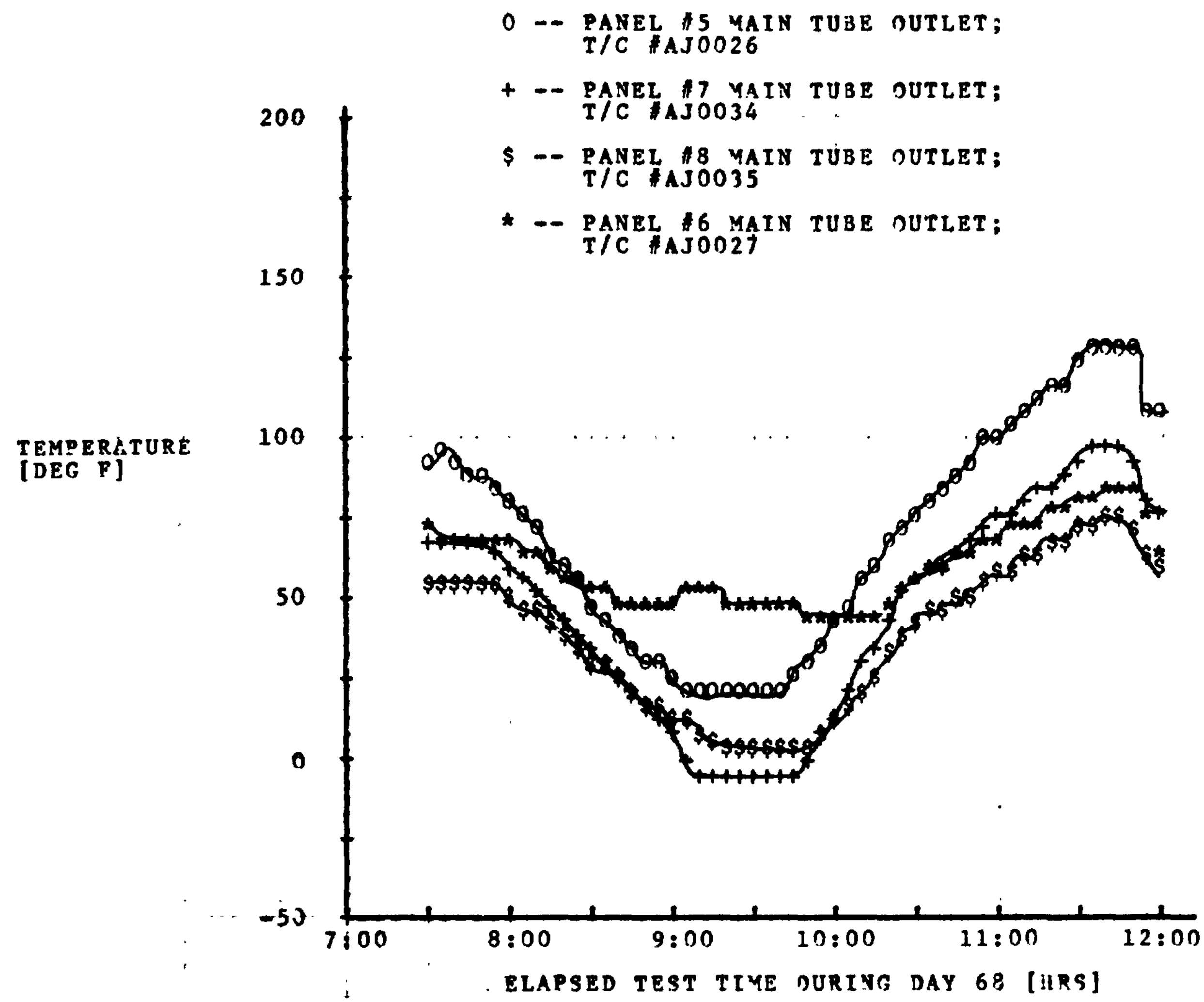


FIGURE 119

TEST POINTS 47, 19 - TEST SUMMARY

TEST POINT	ENVIRONMENT (BTU/hr ft^2)	INLET TEMP(^{0}F)	FLOW RATE DESIRED (ACTUAL)	OUTLET TEMP (^{0}F)	HEAT REJECTED (1000 BTU/hr)
47	124.9 10.9 124.1 7.3 127.6 5.8 125.1 5.1	51.6 → 160 → 50.5	1100 (1099)	Main Prime 49 → 131.6 → 46.9	4.3 → 67.4 → 3.7
19	114.3 35.1 120.5 31.1 16.5 126 12.9 171	162.7 → 52.1 → 161.6	2200 (2163)	72 → 17.4 → 72	51.3 → 9.6 → 50.9

FIGURE 120

TEST POINT 50 - PANEL 2 RECOVERY

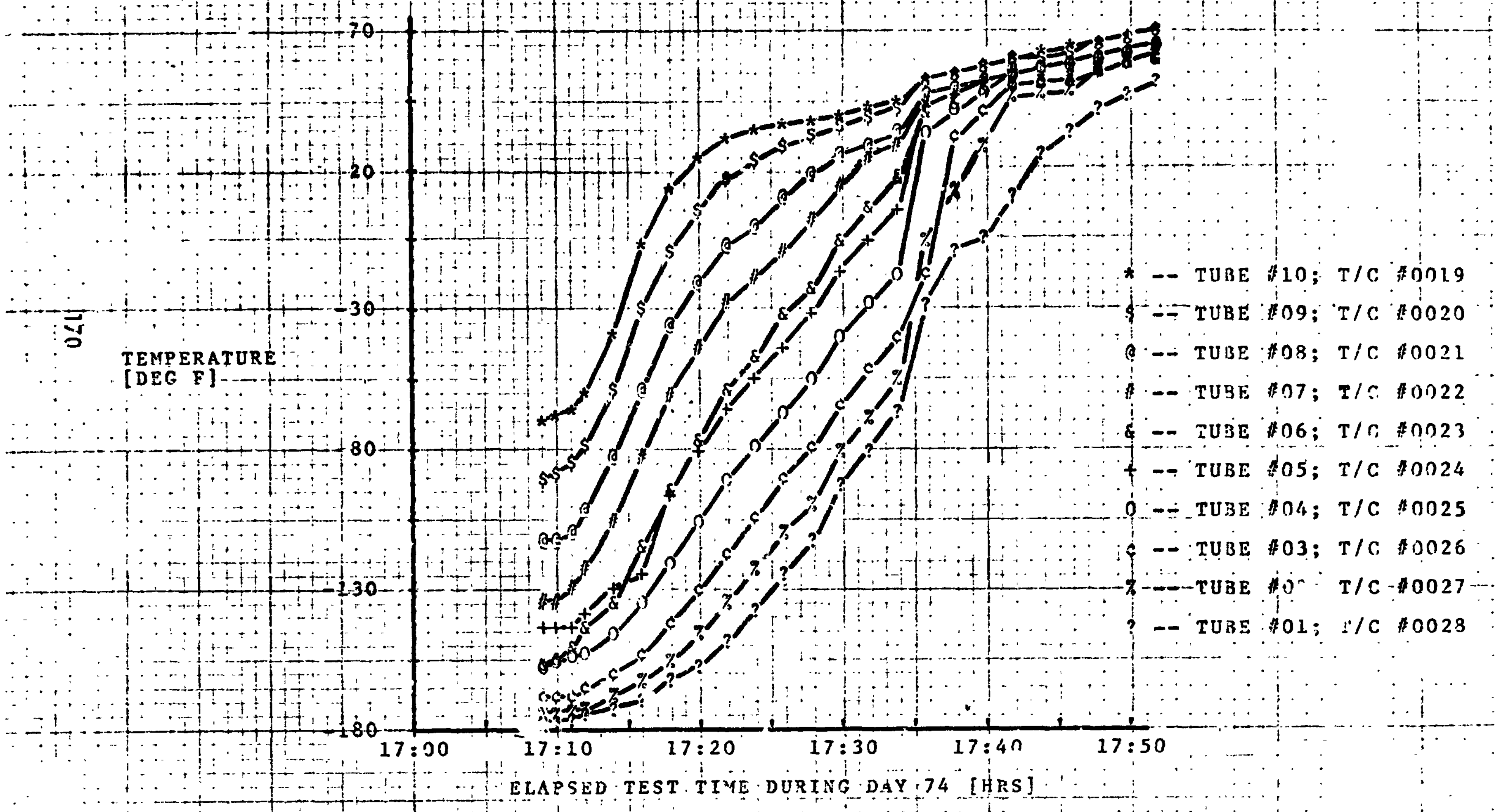


FIGURE 121

TEST POINT 50 - PANEL 3 RECOVERY

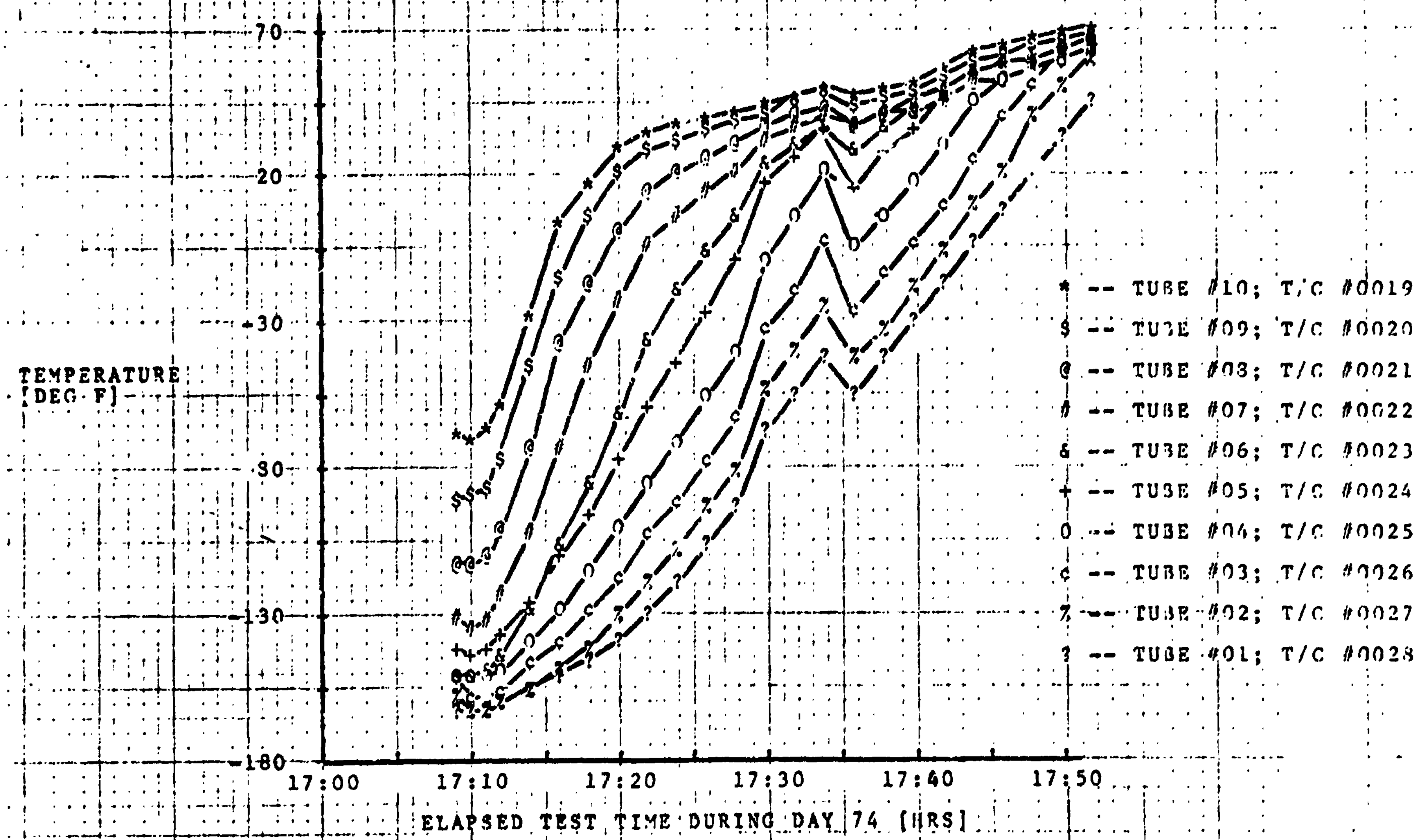


FIGURE 122

TEST POINT 50 - PANEL 5 RECOVERY

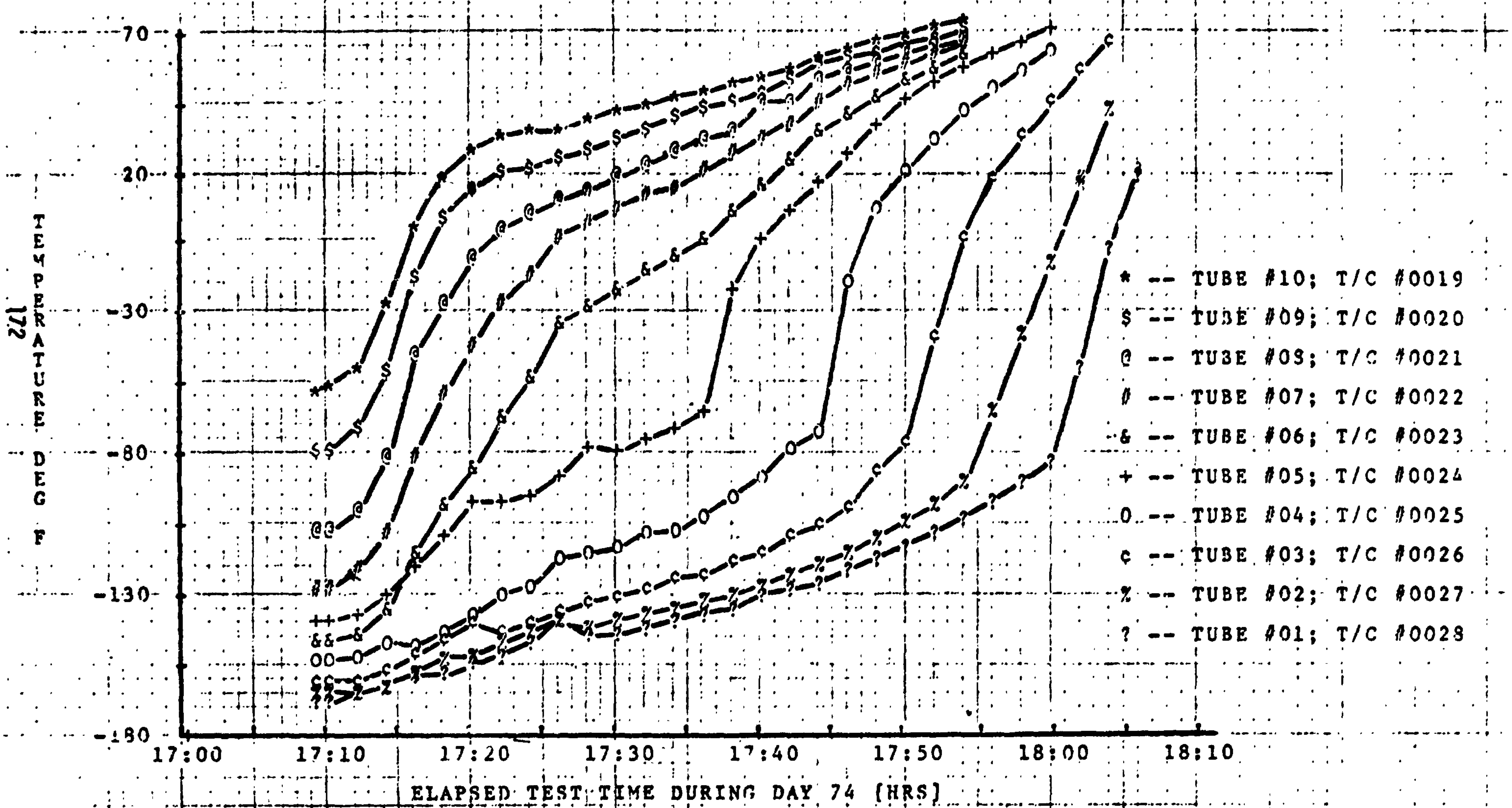


FIGURE 123

TEST POINT 50 - PANEL 6 RECOVERY

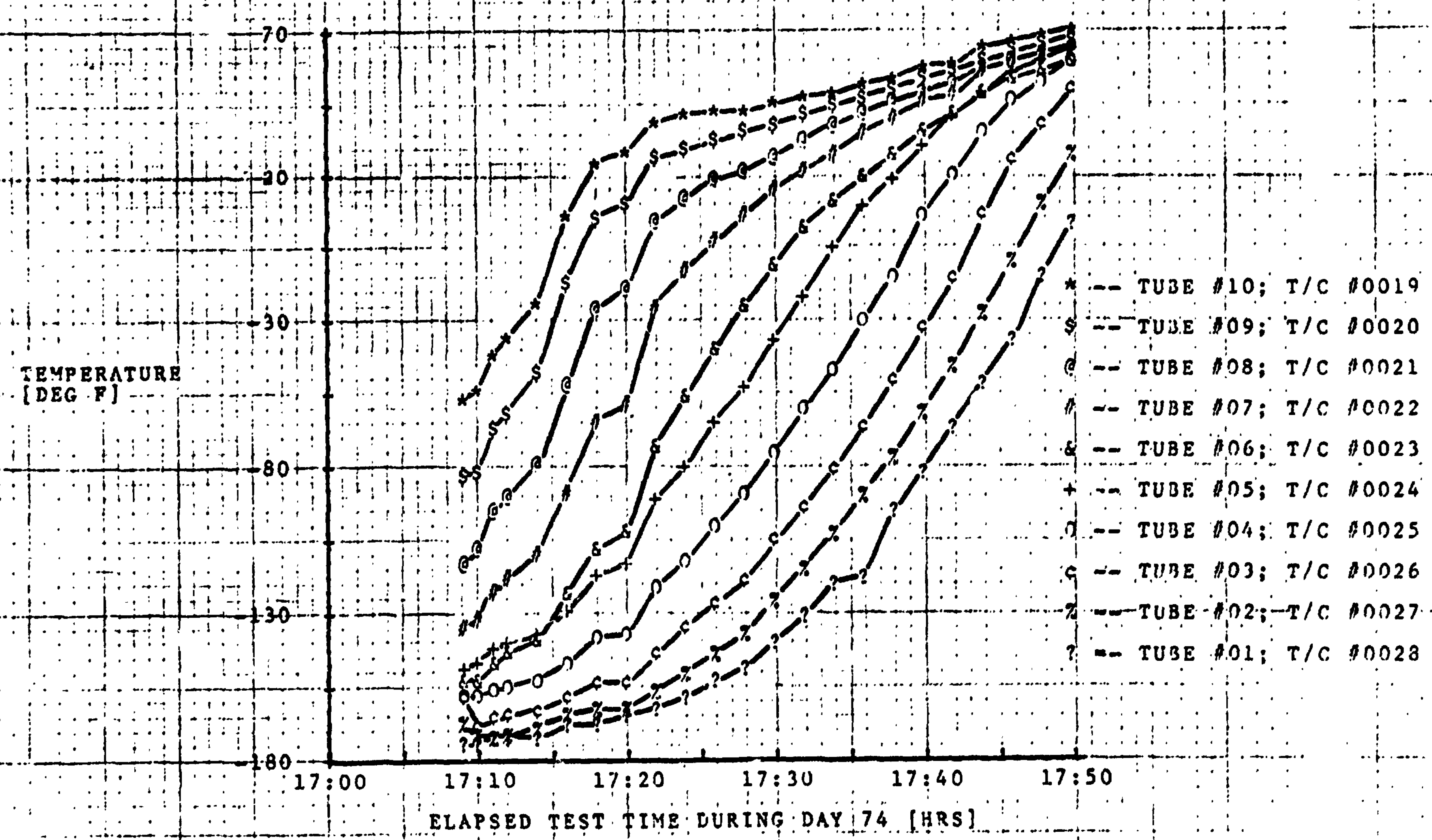


FIGURE 124

TEST POINT 50 - COMPARISON OF TUBE 3
TEMPERATURES DURING RECOVERY

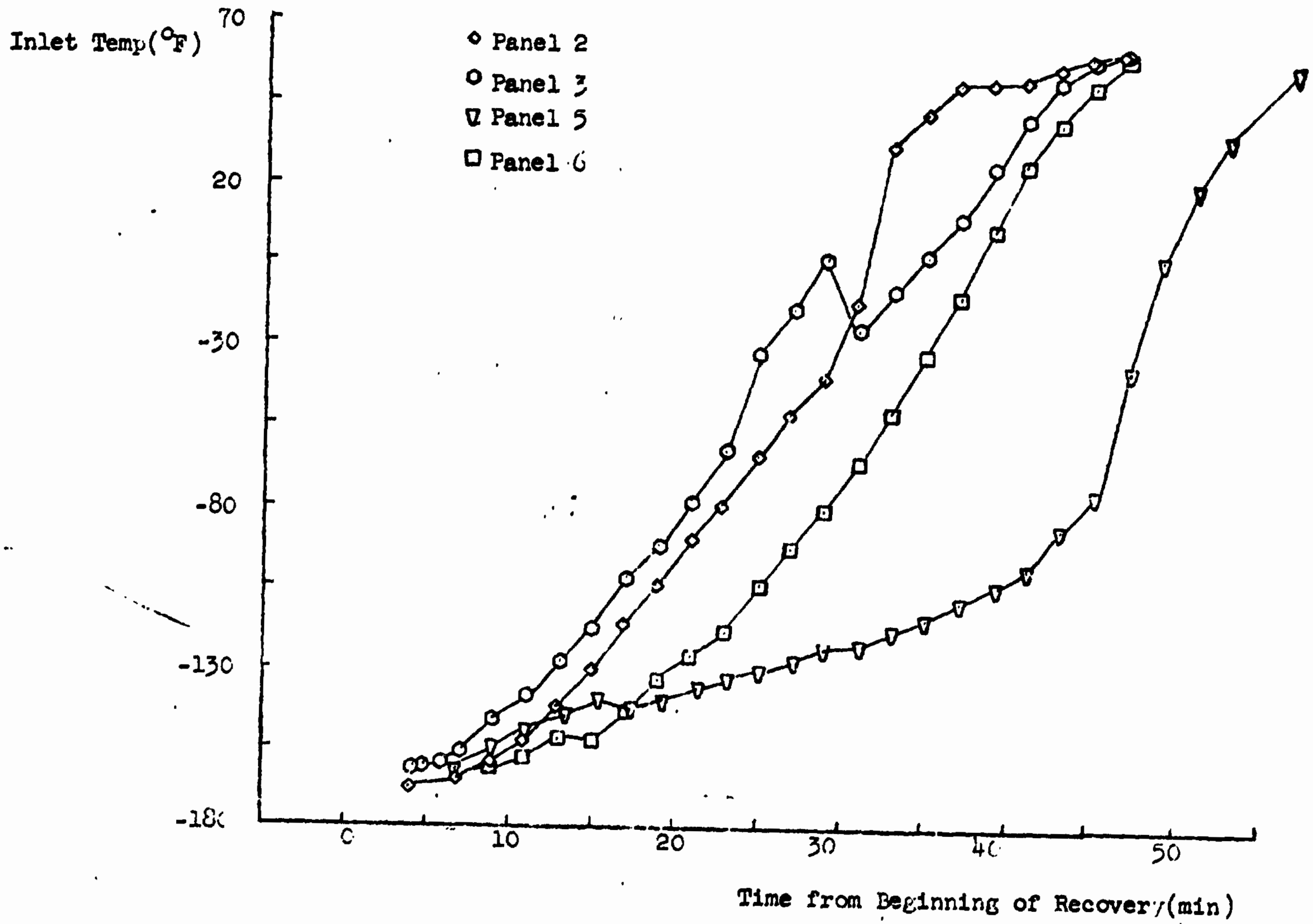
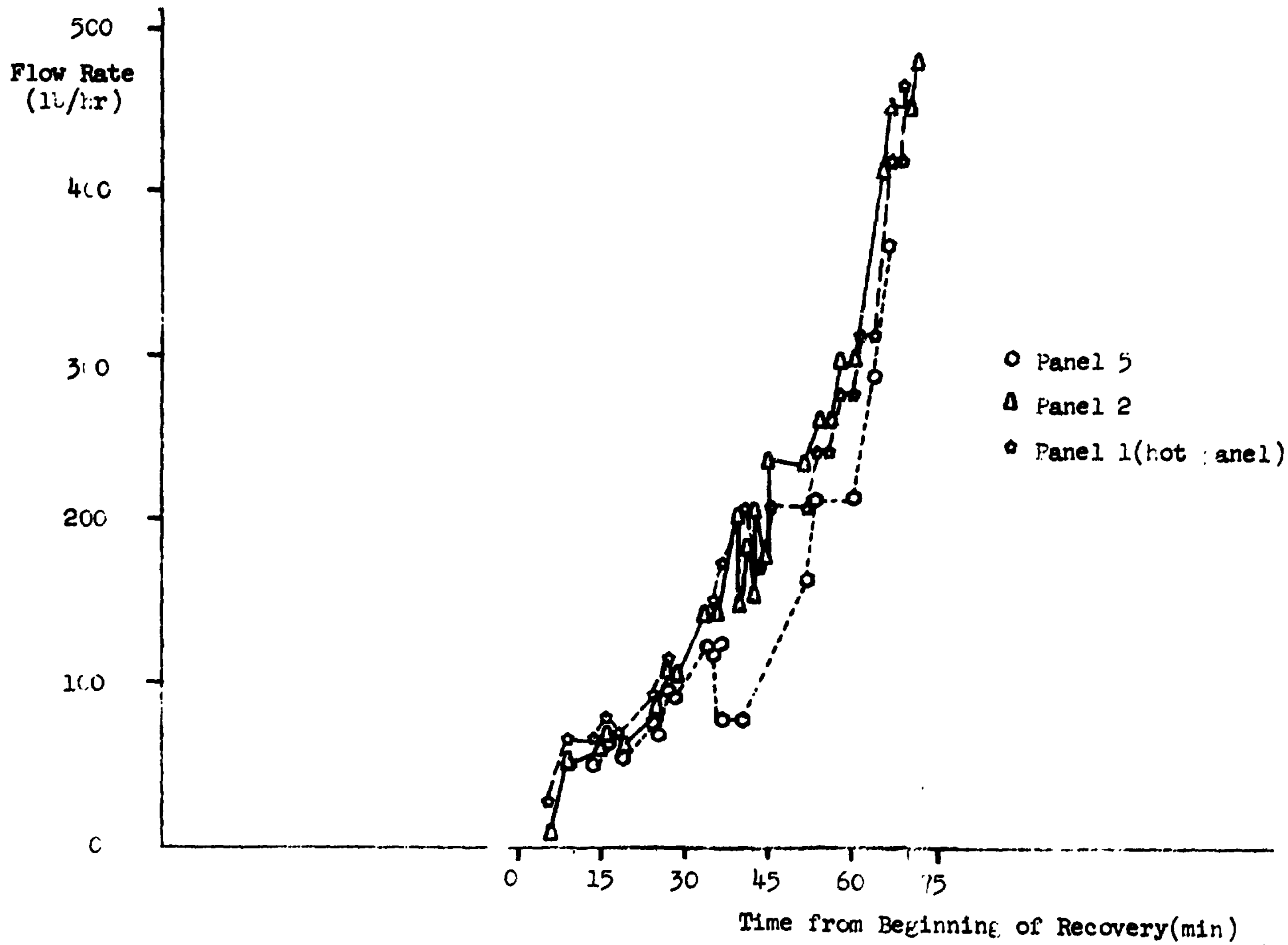


FIGURE 125

TEST POINT 50 - COMPARISON OF PANEL FLOW RATES



K+E 10 X 10 TO THE CENTIMETER 46 1513
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURE 126

TEST POINT 17A - 18 - LEG FLOWRATES
DURING RECOVERY

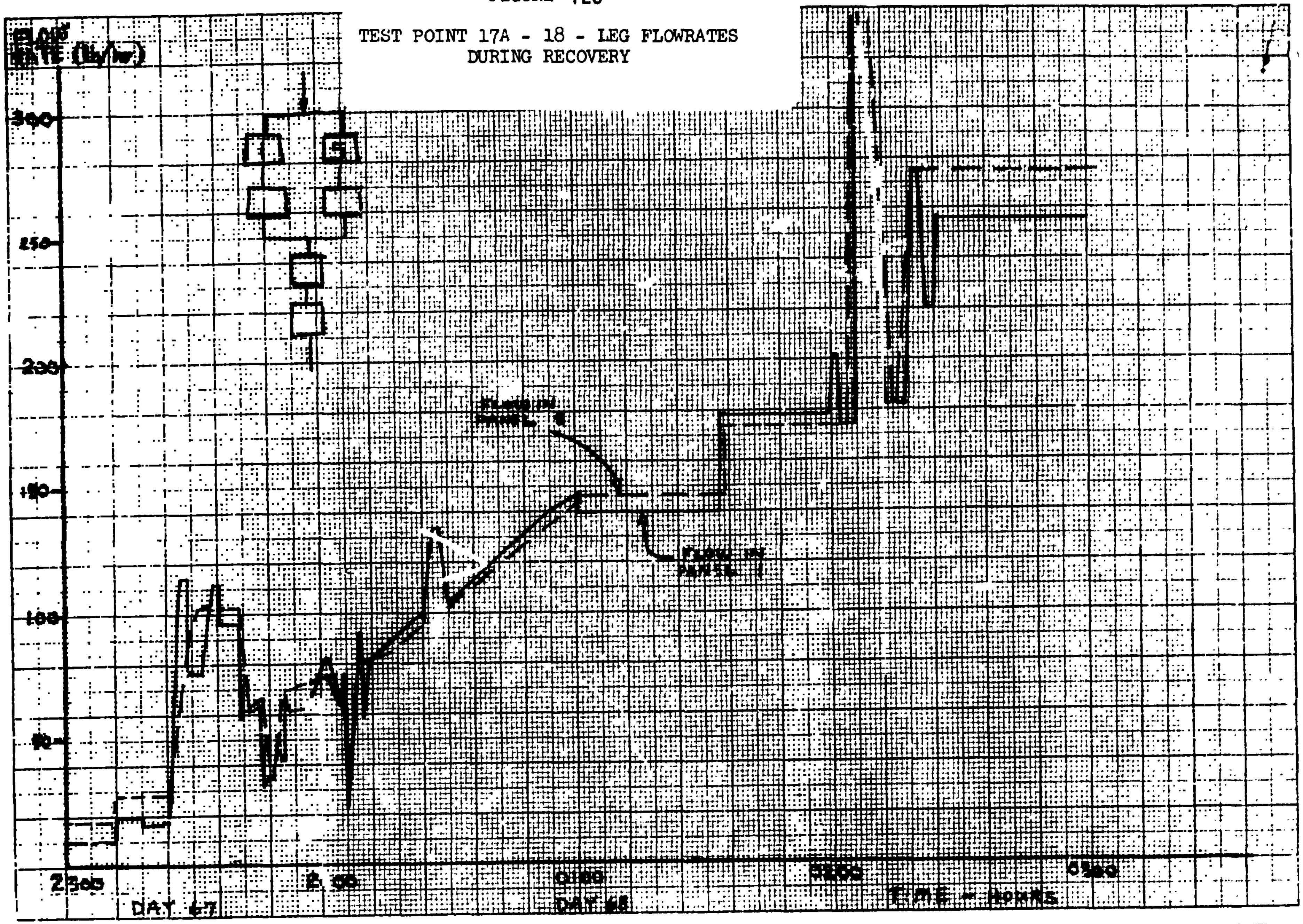


FIGURE 127

TEST POINT 36A - PANELS 2, 5, 6
FLOWRATES

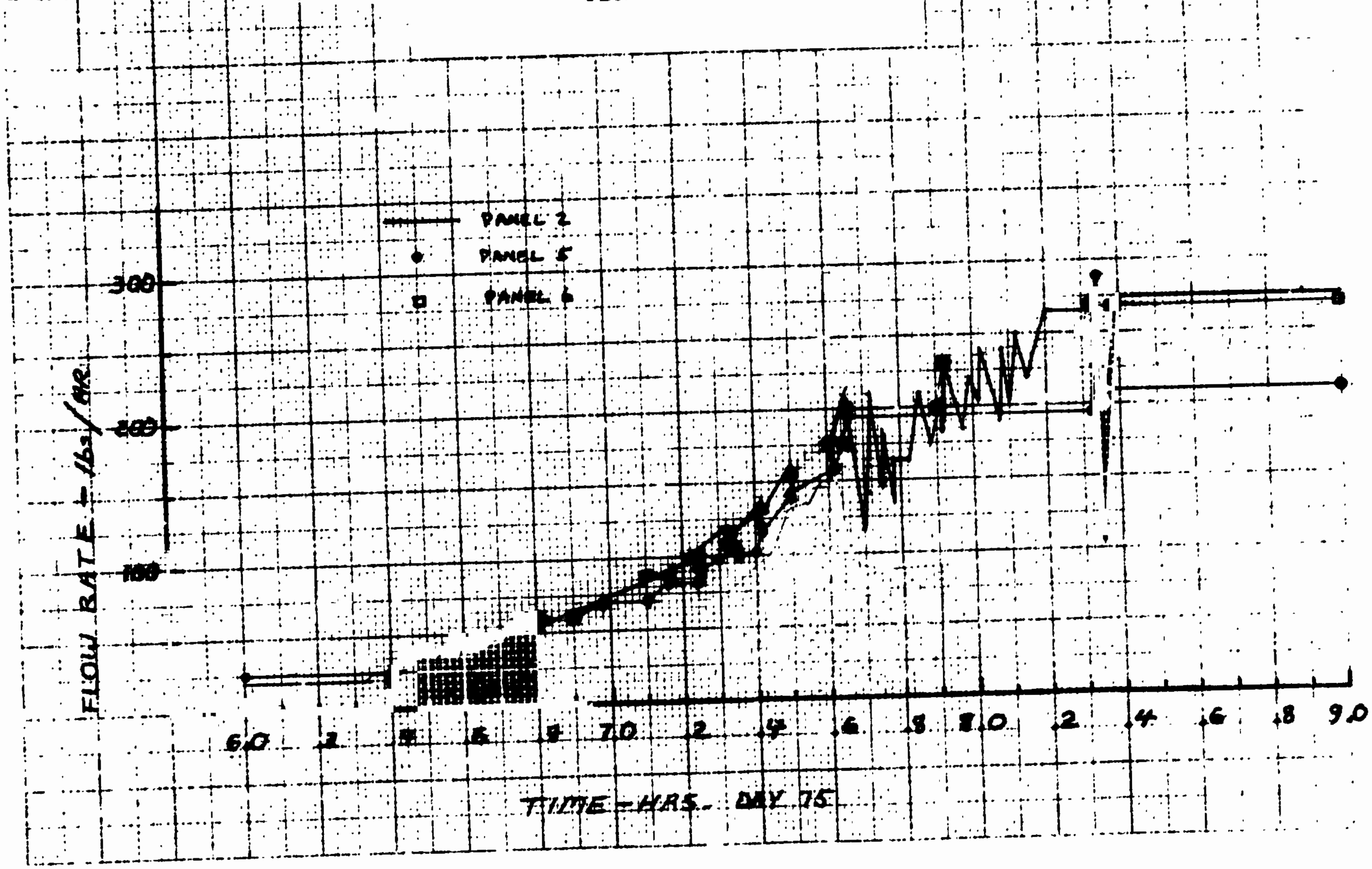


FIGURE 128

LEG FLOW RATES FOR TEST POINT 60-51

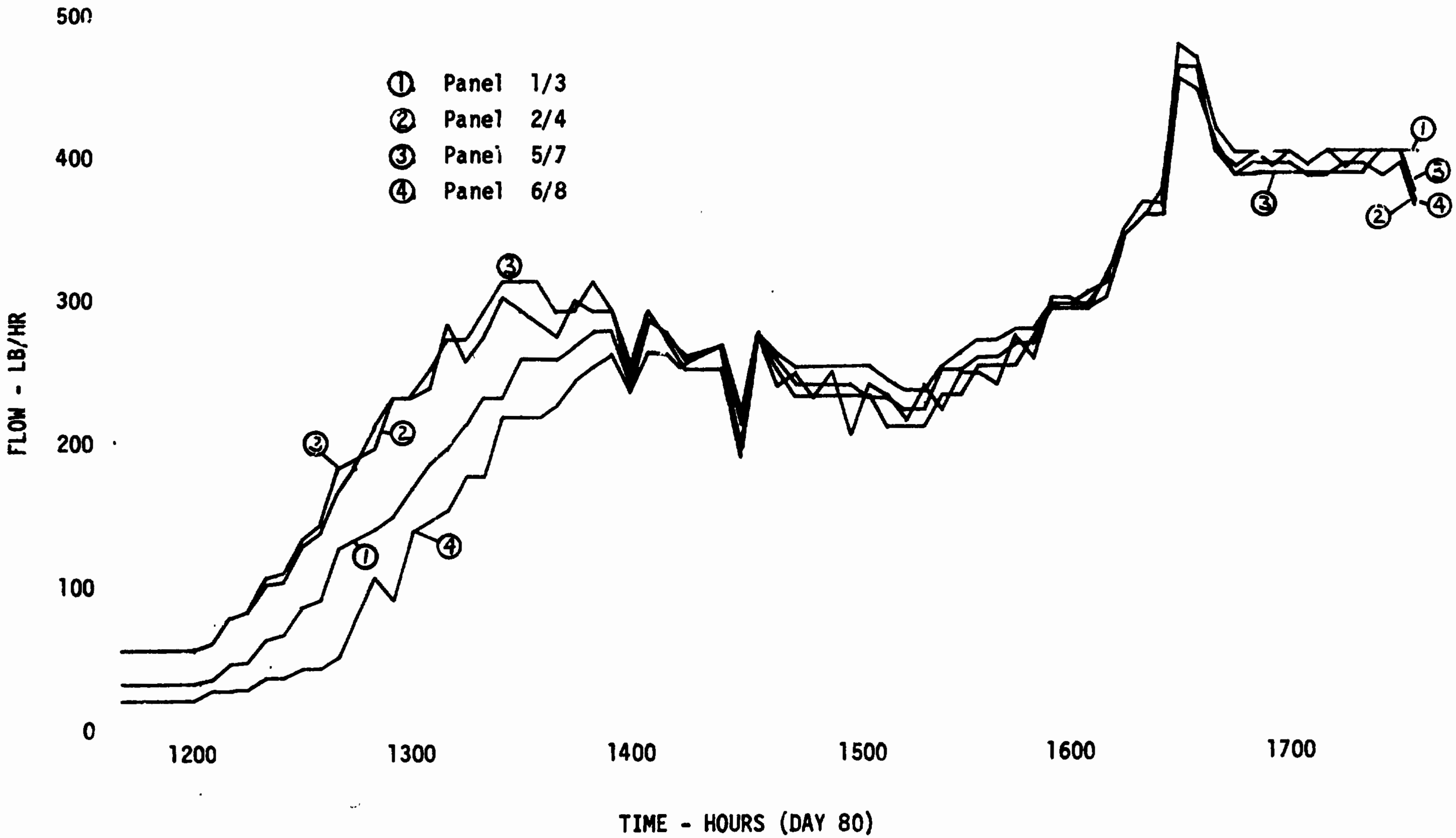


FIGURE 129

TEST POINT 31 - STABILIZED TEMPERATURES

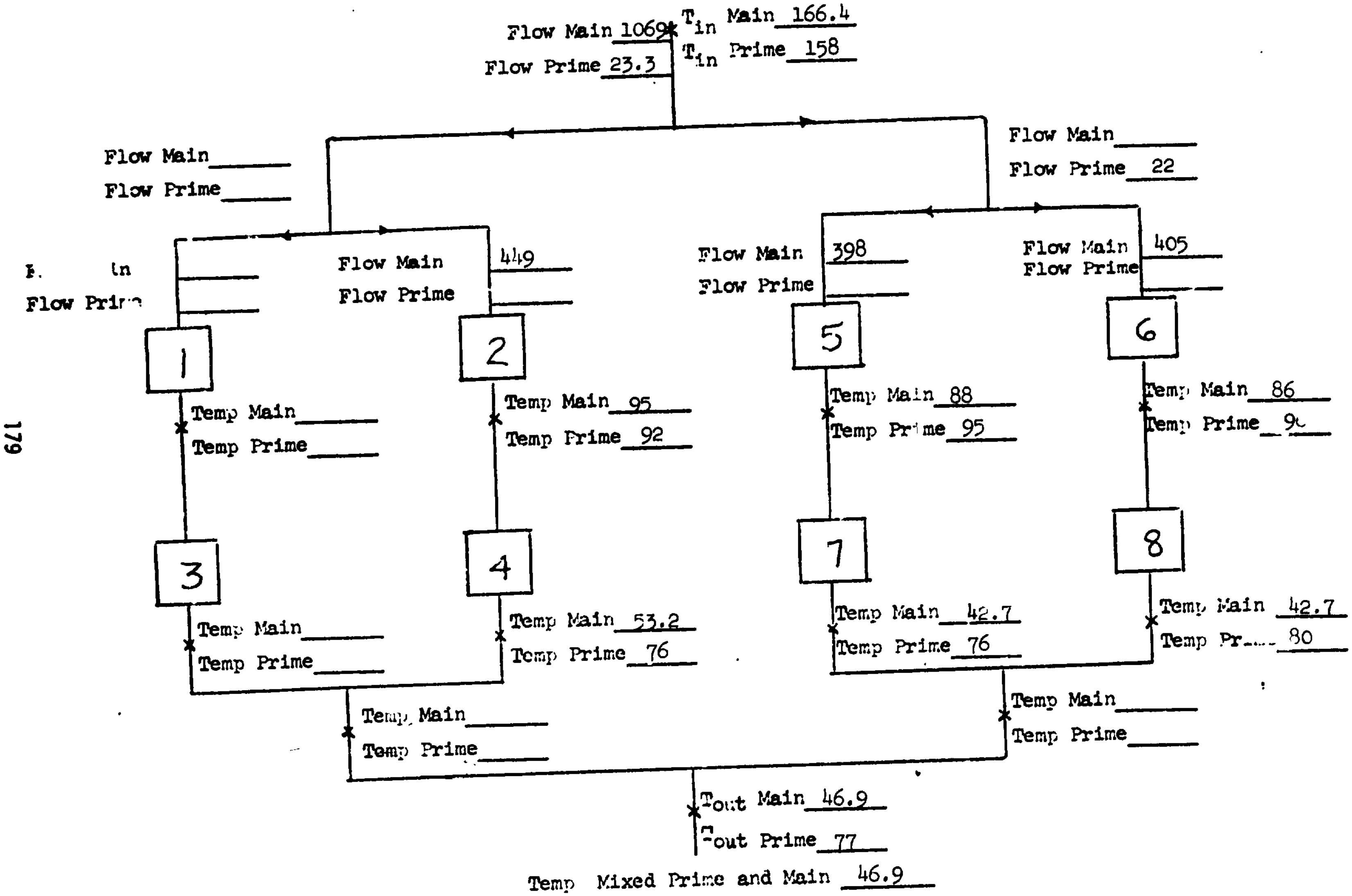


FIGURE 130

TEST POINT 36 - STABILIZED TEMPERATURES

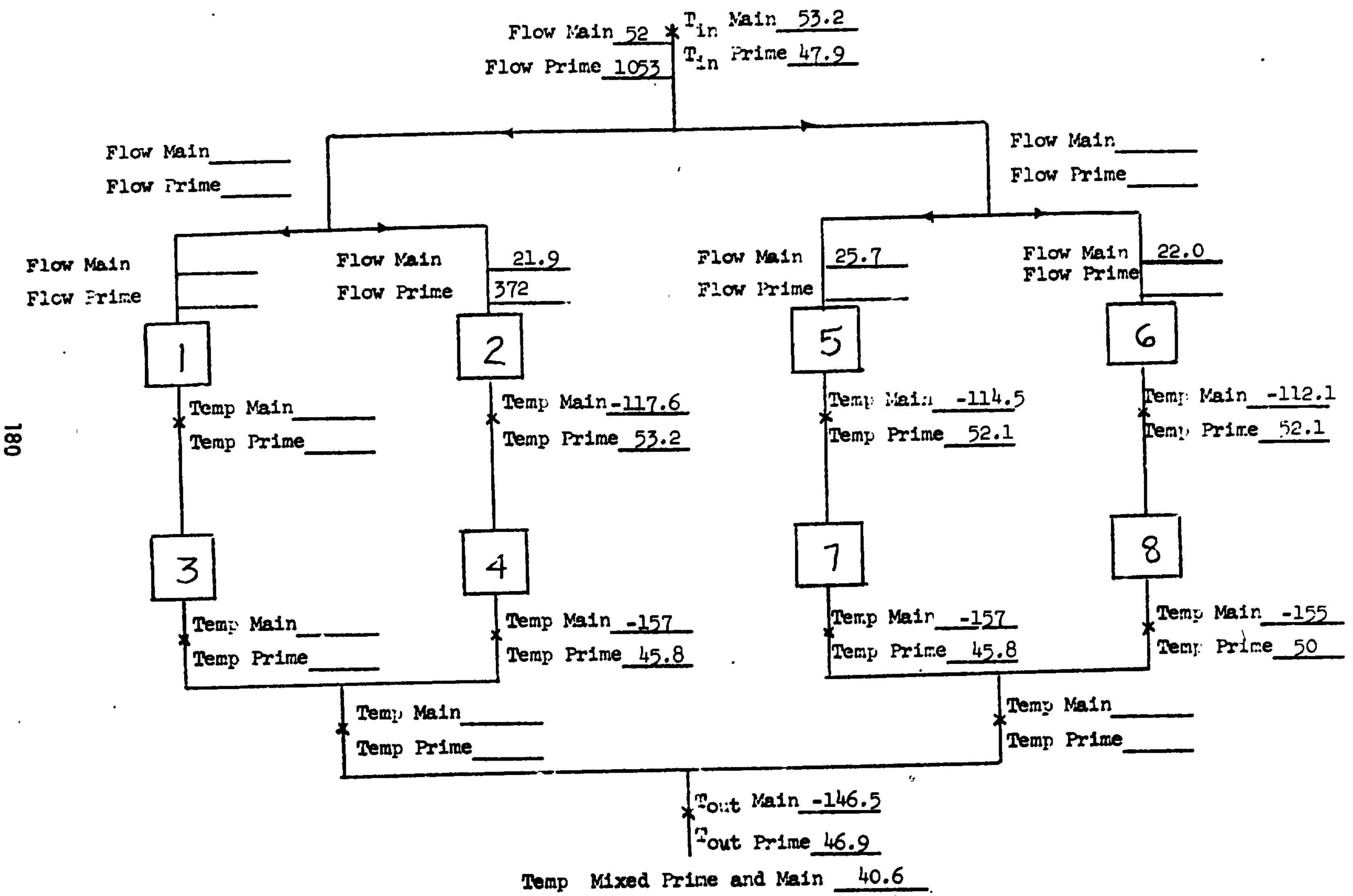
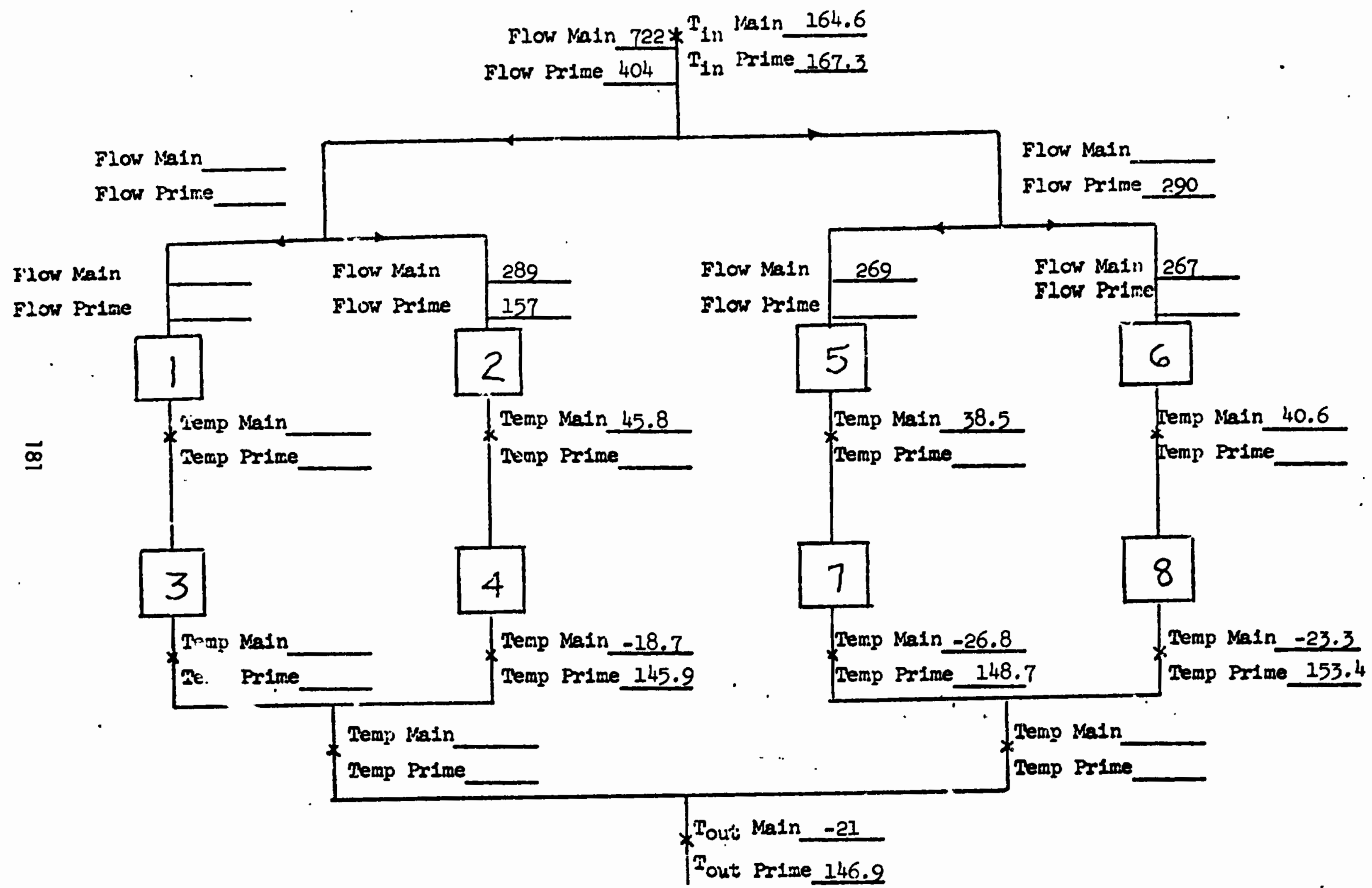


FIGURE 131

TEST POINT 36A - STABILIZED TEMPERATURES



Temp Mixed Prime and Main 39.5

FIGURE 132

TEST POINT 2-1 - STABILIZED TEMPERATURES

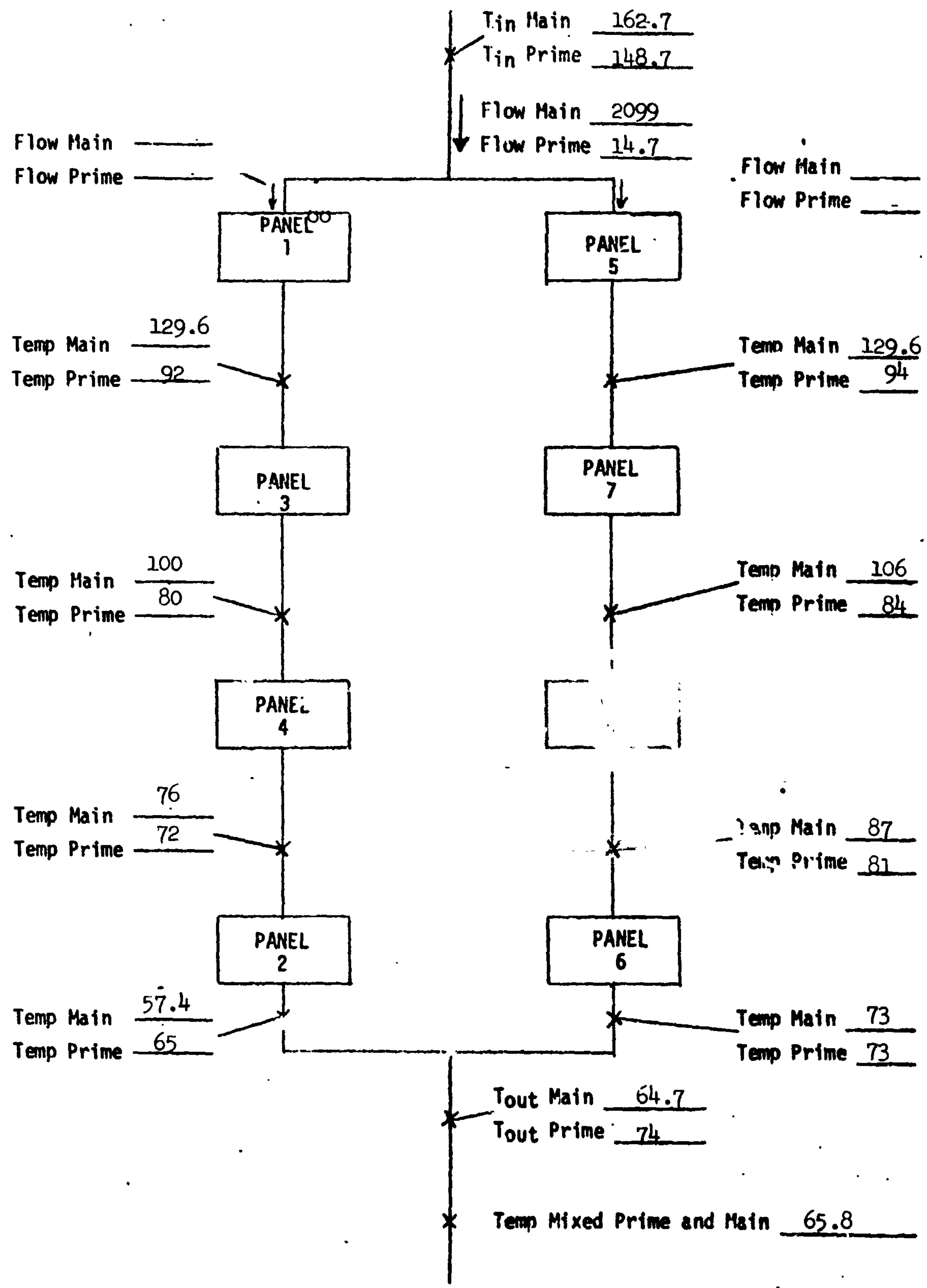


FIGURE 133

TEST POINT 2-2 - STABILIZED TEMPERATURES

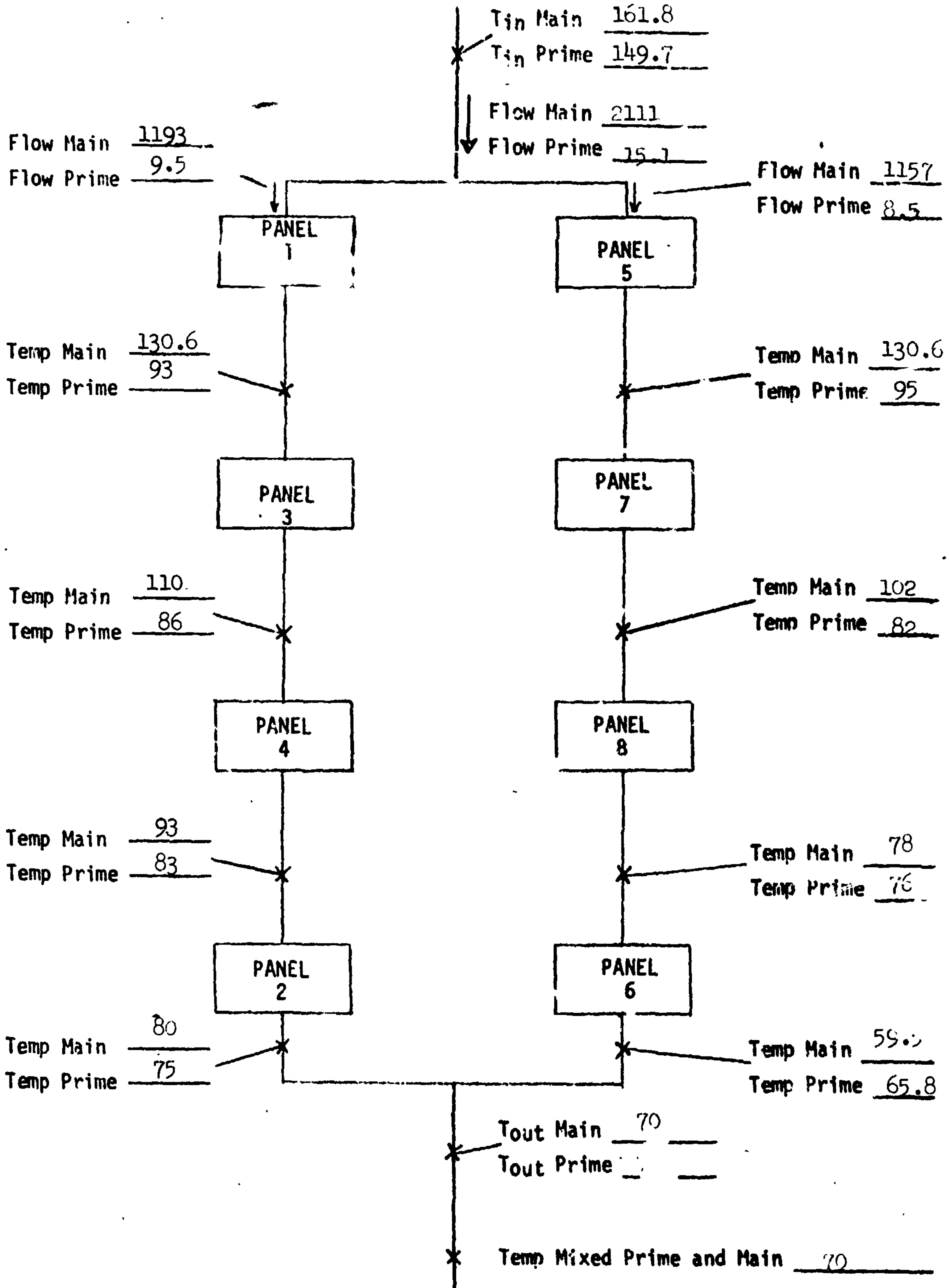


FIGURE 134

TEST POINT 2 - FLOW RATES

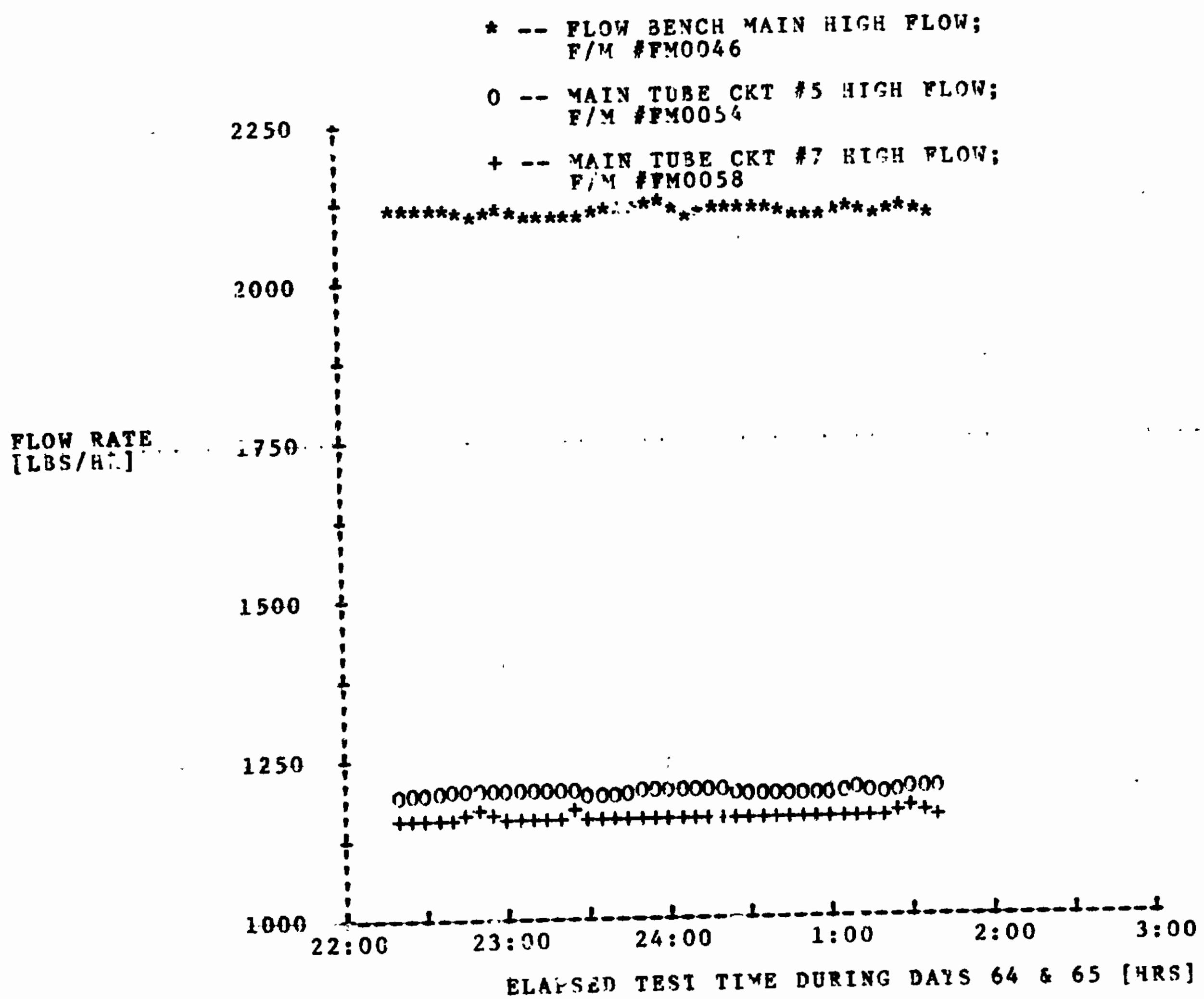


FIGURE 135

TEST POINT 2 - PANEL AND MIXED OUTLET TEMPERATURES

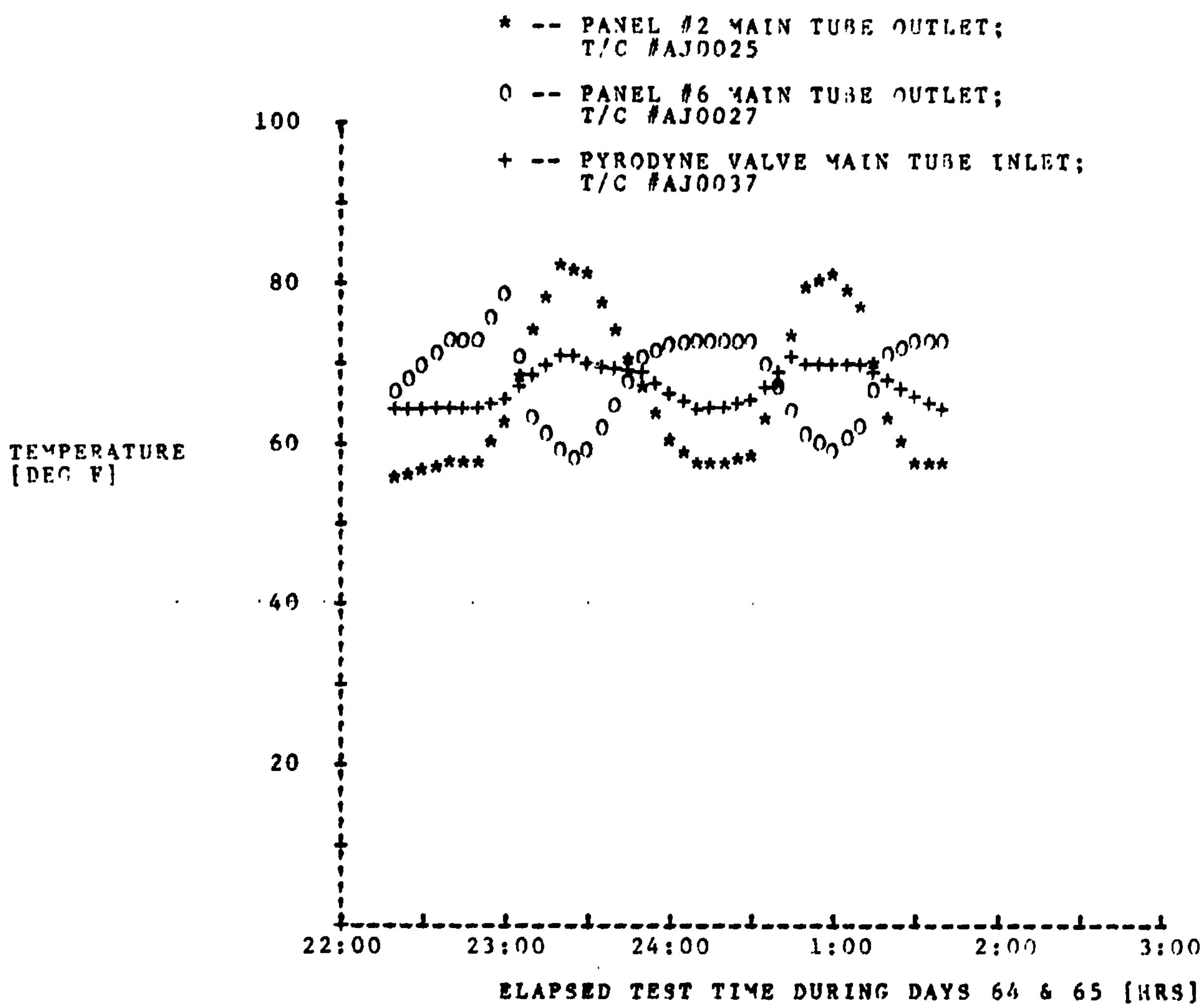
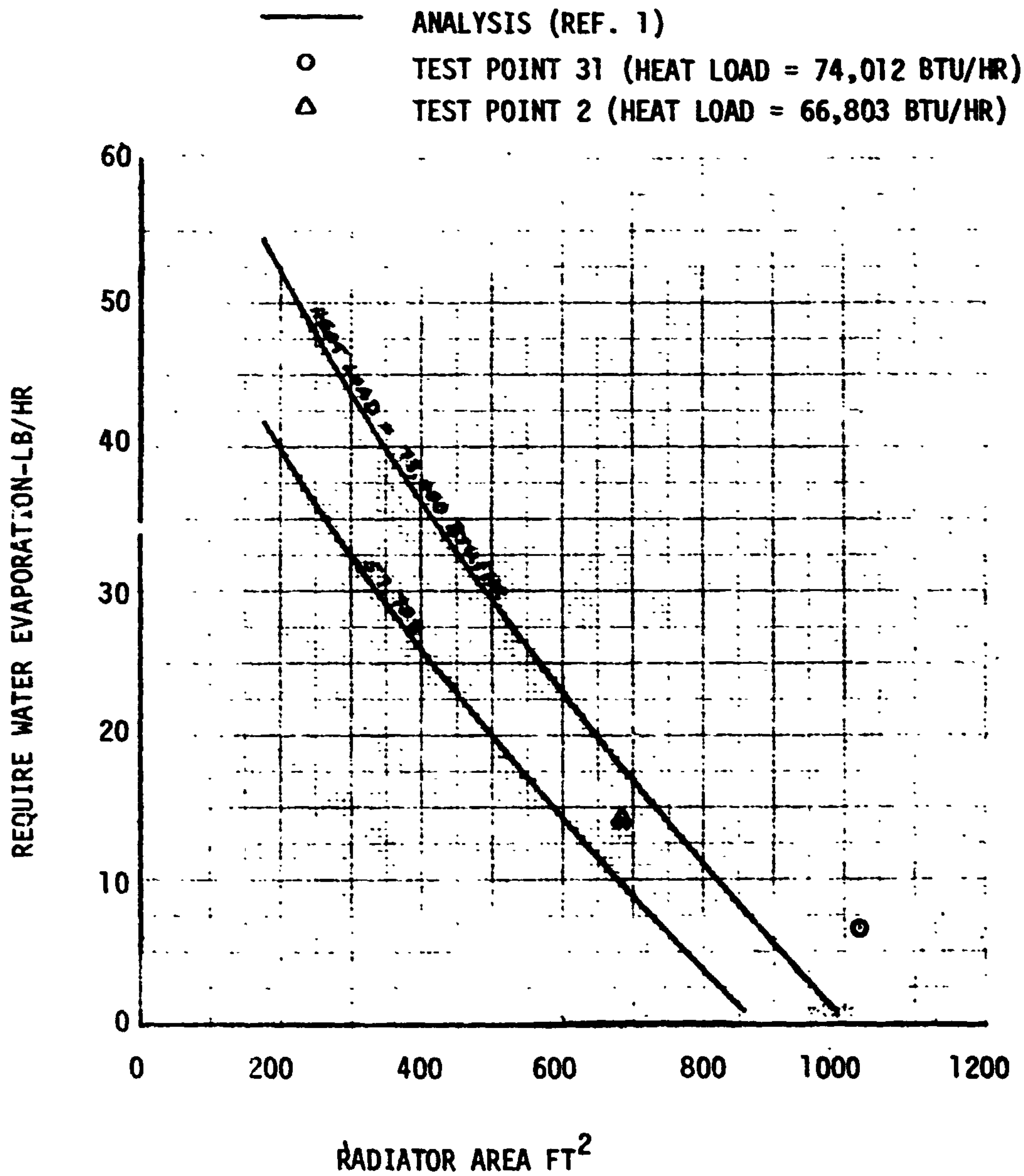


FIGURE 136

COMPARISON OF SIMULATED LOW α/ϵ COATING
TEST RESULTS AND ANALYSIS



APPENDIX A
ENVIRONMENT SUMMARY

TEST POINT	TIME			AVG IR ABSORBED BY PANEL							
	DAY	HR	MIN	1	2	3	4	5	6	7	8
1	64	18	55	137.6	137.5	137.3	137.0	137.5	137.4	138.2	137.4
1A	64	20	00	135	136.6	133.6	135.6	136.4	136.6	135.4	135.5
2 Low	65	01	45	60.8	39.2	39.7	36.2	59.6	71.4	71.6	70.3
2 High	65	01	05	65.6	76.7	76.9	80.5	64.8	45.1	45.8	46.1
5-1	66	19	05	122.4		119.3		125.1	13.8	125.4	15.8
5-2	66	18	00	125.1		122.6		124.5	58.7	131.0	593
8-1	67	04	30	138.4	15.3	140.1	15.9	141.2		141.2	
8-2	67	03	40	138.4	56.6	140	58	141.2		140.1	
10	67	07	55	45.1		34.8	30			32.6	
12	67	11	15	32.8	7.4	31.8	7.9	30.7		31	
3	65	04	45	135.3	136	139.7	136	142.6	138.2	141.8	144.2
4	65	06	00	132.6	140.5	135.5	134.7	134.5	139.4	134.9	134.4
17	67	15	25	28.8		26.6	21.2			21.8	
17A	67	23	00	26.4	5.1	25.1	3.4			21.7	4.2
18	68	03	40	31.7	6.5	28.6	7.2	26.6	12.9	26.5	4.4
19-1	68	05	30	114.6	15.1	119.6	18.7	39.8	175.2	34.5	113.9
19-2	68	09	30	112.3	8.5	120	11.9	25.9	157	24.4	110.4
19-3	68	11	40	116	15	121.9	18.8	39.6	180.6	34.4	126.6
47 Low	71	14	50	126.2	126.6	125.0	129.6	5.8	2.8	3.5	2.95
47 High	71	17	55	127.4	124.6	122.3	125.5	20.4	8.6	13.97	10.78
47 Low	71	20	30	126.3	124.0	124.9	127.7	6.6	3.8	4.5	3.8
14	72	03	15	30	180	30	180	30	30	30	30
14A High	72	06	15	30.3	172.2	30.7	171.6	30.9	31.4	9.4	26.2
14A Low	72	05	35	30.4	33.3	30.8	29.9	30.9	154.4	9.5	152.1
16-1	72	09	55	25.2	561	25.4	556	25.6	32.1	4.0	33.5
16-2	72	09	10	25.4	28.2	25.4	29.7	25.6	63.1	4.0	55.0
20-1	72	12	45	126.8	30.6	124.7	32.9	123.5	79.7	127.1	74.6
20-2	72	13	35	123.5	56.5	124.6	56.4	122.7	32.3	123.0	39.1
20-3	72	14	20	126.8	30.1	126.3	32	127.6	76.4	127.2	78.1
20-4	72	15	10	123.5	53.2	120.5	55.5	125.1	33.5	120.6	36.5

APPENDIX A (Cont'd)

TEST POINT	TIME DAY	HR	MIN	AVG IR ABSORBED BY PANEL 1	2	3	4	5	6	7	8
11	72	18	30	28.5	180.4	28	182.3	23.5		29.2	
31	73	15	25	120.6	59.3	120.7	55.3	61.2	51.7	52.3	52.5
32	73	18	25	130.5	129.3	130.8	130.2	129.1	128.5	130.8	129.6
33	73	19	20	128.7	129	130.3	131.2	129.0	129.2	78.7	129.8
48	73	22	10	128.1	128.5	29.5	29.8	130.5	129.1	78.7	83.6
49	73	23	30	127.5	128.4	29.5	29.5	128.8	129.3	78.2	75
37	74	02	10	110.5	109.6	110	109.8	110.5	109.3	25.1	24.9
38	74	03	00	110.3	111.7	111.1	109.7	110.5	109.2	25.3	24.8
39	74	04	00	109.8	110.5	110.7	110.7	110.6	111.7	26.6	
45	74	06	15	129.4	129	130.1	128.9	128.3	127.2	129.3	128.1
46	74	07	45	130.5	130.3	130.5	118.5	128.3	129.4	118.4	118.8
50-1	74	13	55	125.6	6.2	6.4	120.5	6.3	5.9	118.9	120.5
50-2	74	17	05	126.5	3.2	3.2	119.6	3.4	3.2	118.8	119.3
50-3	74	19	00	139.2	20	18.7	119.7	18.7	19.1	118.8	118.2
43	74	23	00	19.1	4.6	3.5	16.7	4.7	5.0	46.4	56.4
36	75	06	00	113.4	4.8	119.6	2.9	4.8	4.6	3.0	3.1
36A	75	10	00	118.7	17.6	110.1	10.1	16.7	17.0	9.6	9.8
21	78	10	00	161.6	161.7	161.1	161.5	158.6	161.6	159.3	160.9
22 Low	78	13	30	162.5	161.6	161	161.3	128.9	127.6	128.1	128.6
22 High	78	12	30	132.2	132.4	131.5	133.6	168.9	169.5	168.8	173.8
23 Low	78	14	50	159	160	159	159.5	127	127	129	130
23 High	78	15	40	130	130.7	129.9	133.7	171	167	171	167
24 Low	78	19	20	155.6	154	154	157	124	129	127	122
24 High	78	20	10	126	124	125	125	168	163	166	167
25 Low	78	21	45	126	125.4	127.3	129.4	165.7	167.5	167.4	163.7
25 High	78	22	35	151.1	151.2	153.3	153.5	119.5	126.2	124.7	128.9
26	79	01	30	167	169	168	171	65	67	68	69
27	79	02	50	170	170	172	174	66	67	68.8	67
28	79	05	25	164.8	167	164.7	171.5	66.7	69.1	68.7	69.4
29-1	79	09	35	37.3	40.6	40.3	39.5	20.5	21.3	22.1	22.1
29-2	79	10	20	24.3	25.3	25.3	26.7	37.5	38.3	35.2	36.4

APPENDIX A (Cont'd)

TEST POINT	TIME			AVG IR ABSORBED BY PANEL							
	DAY	HR	MIN	1	2	3	4	5	6	7	8
62	80	00	45	2.6	3.1	2.4	2.6	2.9	2.9	2.6	2.3
57	80	04	20	4.5	5.2	2.8	3.1	5.4	4.0	3.1	2.6
58	80	07	35	2.7	2.9	2.5	2.7	2.8	2.6	2.0	2.4
60	80	11	40	4.5	5.0	2.8	3.0	5.3	3.8	3.0	2.4
51	80	17	35	16.5	16.8	8.8	9.2	16.0	16.3	9.0	9.1
52	80	19	20	93	10.3	5.3	5.5	10.0	10.2	5.3	5.4
52A	90	20	30	6.3	6.5	3.4	3.6	6.6	6.6	3.5	3.4
52B	80	21	00	6.5	7.0	3.4	3.7	6.8	6.9	3.6	3.6
52C	80	21	55	6.3	6.5	3.2	3.5	6.2	6.3	3.5	3.4
52D	80	23	35	3.5	3.7	2.9	3.0	3.9	3.6	2.9	2.9
52E	81	02	05	6.7	6.9	3.3	3.9	6.9	7.0	3.7	[illegible].4
53	81	07	15	126.5	125.7	120.7	114.2	14.0	14.0	7.4	7.2
54	81	08	25	130.2	128.6	124.1	123.4	17.5	17.6	10.7	10.6
55	81	09	20	129.9	128.2	123.7	123.8	17.6	18.2	10.5	10.5
56	81	11	05	124.8	124.8	119.8	121.5	13.9	13.7	7.3	7.0
59	81	12	10	129.3	128.7	124.9	124.1	17.3	18.7	11.1	11.1
63A	81	18	55	151.1	151.2	151.1	151.3	151.8	151	151.1	150.8
63B	81	19	30	135.1	134.3	135.4	134.7	38.1	40.3	29.3	30.6
63C	81	20	15	38.2	37.3	27.9	28.8	35.6	36.5	26.7	27.9
63D	81	21	00	37.2	36.7	28.3	28.5	140.6	133.3	139.2	136.6
63E	81	21	44	151.8	152.9	153	156.2	152.9	149	149	149.8
64A	81	23	45	133.1	133.2	132.4	132.7	34.9	36.7	27.3	28.2
64B	82	00	20	49.5	47.7	51.2	50.2	46.0	34.2	25.8	26.1
64C	82	01	02	171.2	172.5	161.5	176.8	60.2	58.1	58.9	59.3
64D	82	01	25	142.5	143.5	140.3	144.3	71.9	69.3	70.9	72.3
64E	82	02	00	134.1	135.3	133.6	132.9	35.2	36.5	22.7	28.3
61A	82	04	15	57.5	59.1	58.9	58.8	167.6	167.6	166.6	164.6
61B	82	05	00	54.4	55.0	54.4	55.0	59.7	55.3	58.4	54.9
61C	82	05	55	169.2	171.4	161.5	175.6	57.3	55.2	59.3	62.4
61D	82	06	30	158.8	153.0	160.5	161.4	162	160.8	149.4	167.3

9 March 1973

MRS Shuttle Test Operations Report # 1

The first of three planned weeks of test operations were successfully completed on 9 March 1973. Because of facility leakage and flux simulator problems and resulting damage to insulation blankets, test time available was severly restricted and all objectives were not accomplished. Testing in the first week configuration will therefore be continued next week to accomplish these objectives which are related to investigation of the Baseline flow arrangement operation.

General test operations are summarized below.

Date (day)	Time	Activity
5 March 1973 (64)	00.00 Hrs.	Test team on station.
	03:15	Chamber inspection .
	05:00	Start pumpdown.
	06:05	Chamber back to ambient to fix leak.
	06:25	Start pumpdown.
	07:15	Start MRS flow set-up.
	11:24	Other chamber leakage repaired.
	12:59-13:31	Ace down
	15:10-16:22	Observed erratic pattern of prime tube panel inlet and outlet temperatures -- increased flow from approximately 17 Lb/Hr to 335 Lb/Hr. and established good pattern -- returned flow to normal. Problem due to thermal domination by line heat leaks at very low flow rates. Acceptance because prime heat rejected only 1% of total heat rejected under these conditions.
	15:25	2.5 X 10^{-5} to 10^{-4} torr chamber pressure.

MRS Shuttle Test Operations Report # 1
(continued - page -2-)

5 March 1973(64)	16:57	Temporarily lost all flux simulators. Chamber pressure 2 to 4 X 10^{-5} torr (DTP requires 1 X 10^{-5} torr). 4 X 10^{-5} torr acceptable for this secuence because mean free path is 4.5 ft at 130^{o}F or approximately 10 times distance between radiator and flux simulator.
	18:55	Complete first test point (#1).
	20:20	Complete test point 1A.
6 March 1973(65)	01:46	Complete test point 2(cyclic environment)
	03:17 to 03:36	Ace down
	04:45	Complete test point 3.
	06:00	Complete test point 4.
	07:39	Pyrodyne valve control to 47^{o} to 49^{o}F-- activate ATM valve to achieve 40^{o}F control.
	09:23	Inlet conditions achieved for test point 5 stabalization.
	09:48	Flux simulator 4 sprung a freon 11 leak.
	10:41	Insulation blankets blown off of panel 3 and 4 and partially off of panel 7.
	12:45	Checkout pyrodyne valve-increasing back pressure from 100 psi to 200 psi does not affect set point. Also, checked out ATM valve. Data on voice tape.
	14:50	Chamber repress started.
	24:00	Timeline revisions resolved for reduced available test time this week. SESL used 0.85 assumed panel emmissivity in setting up desired fluxes and LTV used 0.92 in pre-test predictions.

MRS Shuttle Test Operations
(continued - Page -3-)

6 March 1973 (65)	5 paint samples have been shipped from Dallas for measurement by SESL. (Results of measurements made later in this week indicate 0.913 emmissivity , but this is a "near normal" value. Correcting to "Hemispherical" emmissivity yields 0.89. A 0.9 radiosity model that SESL has available should prove adequate for flux simulation analysis).
7 March 1973 (66)04:03	Start pumpdown.
10:25	Freon 11 leak at zone 2 IR simulation. Change flow arrangement to flow through panels 6 and 8 instead of 2 and 4.
19:20	Completed one cycle of TP5 -- Leak developed in IR simulation F-11 zone 8 -- Blew insulation off of panel 8, and slightly off of 6, 7 -- insulation now covers approximately 70% of panel 2
8 March 1973 (67)00:20	Started test point 8 using panels 4 and 2. Revised test plans to achieve maximum useful data with existing facility test set-up.
04:30	Completed test point 8 (β configuration) with degraded insulation on panel 2 and slight degradtion on panel 7.
07:55	Completed test point 10 with a single series flow path through panels 1, 3, 4 and 7 (one half of α configuration) instead of the desired pair of series flow paths 1, 3, 4, 2 and 5, 7, 6, 8. Data is acceptable to satisfy objectives.

MRS Shuttle Test Operations
(continued - Page -4-)

8 March 1973(67)	11:15	Completed test point 12 (B configuration) with degraded insulation.
	15:25	Completed test point 17 (one half of A configuration).
	20:50	Cooldown was speeded up by shutting main flow off for approximately 4 hours. Flow was momentarily cycled on and off twice during this period to insure that local freezing could not occur at a possible heat short. Flow set up to 14 Lb/Hr. in main at 20:50. Data on voice tape.
	22:56	Completed test point 17 a (B configuration) with LN_2 environment on panels 2 and 4. Approximately 5 tubes frozen on panel 4 but degraded insulation prevents proper freezing pattern on panel 2. With 15 Lb/Hr. main flow (-152^{o} outlet) and 1154 lb/Hr. prime flow (49^{o}F outlet). Mixed temperature would be approximately 47^{o}F. This agrees with pyrodyne valve control point. (Actual mixed temperature is 47^{o}F, but this is coincidence because mixed inlets at valve are approximately +25 main and +47^{o}F prime due to line heat leaks). Excessive heat leaks at low flow rates yield the following main inlet and outlet pattern for panels 4 and2; 4 inlet -65^{o}F, 4 outlet -150^{o}F, 2 inlet -118^{o}F, 2 outlet - 152^{o} F.
	Approx. 23:00	Started 3 hour recovery ramp of inlet temperature. Frozen tubes thawed out at expected rate of approximately one every 10 minutes during first hour of recovery. Data on voice tape.

MRS Shuttle Test Operations
(continued - Page - 5-)

9 March (68)	02:04	Activate ATM valve to achieve desired $40^{o}F$ set point for test point 18.
	03:40	Test point 18 complete (β configuration).
	11:40	Test point 19 completed (Full α configuration), with degraded insulation. Prior to this test point panel 8 was completely uncovered for long period with LN_2 flux simulation on one side. Average panel temperature of $-90^{o}F$ indicated that chamber environment in this region of the chamber must be approximately 55-60 BTU/Hr ft^2. Analysis of this data may be used to establish actual environments on panel 8 during test point 19.
	14:00 Approx.	Photographs from top of chamber obtained at LTV request to document condition of blankets prior to repress.
	19:40	Post test inspection -- blankets did blow around during repress. Damage to failed simulator panels at inlet manifolds. Radiator panels OK.

Signed: R. J. Tufte
9 March 1973

16 March 19[illegible]

MRS SHUTTLE TEST OPERATIONS REPORT #2

The second of three planned weeks of test operations was successfully completed on March 16, 1973. Due to flux simulator problems in the first week of testing some of the first week's test points were carried over into the second week's schedule allowing baseline objectives to be accomplished. The planned second week's objectives were for the two sided operation of the panels. Since the important nature of the two sided operation, it was decided to move the second week's configuration to the third week of testing to inable completion of test objectives. All major third week objectives were accomplished during the second portion of the second week. Flux simulation data is being processed much quicker and all data is now available (Friday) on the second week of testing. General test operations are summarized below.

<u>12 March 1973</u> (day 71)

00:00	Test team on station
2:00	Start pump down
2:19	Freon leak detected - secure pump down
3:22	Start pump down
5:58	2 x 10^{-1} torr chamber pressure Stopped flow in MRS to allow coldsoak
6:30-11:35	Flow started for approx. 5 min every 30 min to prevent freezing of connecting lines
11:08	4 x 10^{-6} torr chamber pressure
13:40	Panel 6 has 5 to 6 tubes frozen Panel 8 has flow in all tubes. Suspected ion gage suppling heat source due to bad insulation. Main flow of 111. set by Pyrodyne valve mixing to 45°F. Analytical mix of panel outlet temperatures is 42°F.
14:50	Stabilization reached for TP47A
15:00	Start 2 hour ramp to 162°F
15:30	Panel 6 thawed
15:40	Flowmeter 54 went out
15:54	Shut down main flow to replace FM0054 with FM0056
16:04	Main flow back up
17:00	CRT at flow bench went out
17:28	CRT back on line

18:00	Stabilization reached for TP47B
20:25	Complete inlet temperature stabilization after 2 hour down transient (TP47C)
20:46	Prime bypass via V46 to stay under 325 psi pressure red line
21:00	Pyrodyne valve oscillating, cut oscillations by cutting down main valve
22:55	All flux simulators operating with Freon
23:08	Shut off main flow to allow panels to cool faster
23:32	Re-initiate main flow
23:50	Potential problems on TP (21-1400) (1) insufficient power in 10kw heater to achieve 152° inlet on prime at high flow rates. (2) insufficient GSE heat exchanger to achieve -16°F on main due to high flow. (3) flux simulator #7 cannot maintain temperature control.

<u>13 March 1973</u> (day 72)

03:15	Stabilization reached for TP-14. Main inlet temperature cycling between 23.7 and 20.5. Flux simulator 7 set to LN_2 for freon loop trouble shooting
06:15	Two 90 minute cycles completed for TP-15. Start inlet temp & IR transients to TP-16 conditions
07:30	Cycle started for TP-16
08:40	FCE reported a Freon leak
09:50	Flowmeters for panels 1 and 5 were not on line. No flow distribution measurements for this TP. Freon 11 pump on panel 7 reported fixed
10:40	Completed TP-16; V-45 was open during TP-16; prime flow bypass to obtain 2200 lb/hr
12:46	FM0042 and FM0047 went out
15:15	Completed TP-20 - cyclic α_3 Setup β for 21-1100; fixed the two flowmeters
17:30	Inlet temp cycling ± 5° in response to coldpack cycle with full heater bypass
18:30	Completed TP-11; start repress

<u>14 March 1973</u> (day 73)

01:32	Chamber door open
06:30	Start pump down. Lines have been changed and system pressure checked.
08:50	Panel 7 ΔP measurement bad
09:40	Artificial flow balance was performed at ambient conditions with all panels flowing. Total flow = 2200 lb/hr
	Switched back to γ-1,-3 and 1100 lb/hr
10:40	Activate Pyrodyne valve to reduce pr[illegible]e flow to 20-30 lb/hr
10:45	Pyrodyne valve restricted total flowrate to 200 lb/hr; took it out of circuit
11:15	Trouble reported with FM46
11:24	FM46 fixed
14:00	IR fluxes low on panels 7 and 8 started bringing up to correct positions.
	This test point demonstrates the low α/ε coating on the total cargo bay door area with the forward doors opened farther than aft doors (different sun angle) will accomplish approximately 70k heat load in direct sunlight.
15:25	Completed TP-31 (γ-1,-3 panels)
17:00	IR zones set to 130 BTU/hr-ft^2
18:25	Completed TP-32 (γ configuration)
19:20	Completed TP-33 (δ configuration)
22:10	Completed TP-48 (δ configuration)
23:30	Completed TP-49 (γ configuration)
	Proceed to TP-37

<u>15 March 1973</u> (day 74)

02:10	Completed TP-37 (γ configuration)
03:00	Completed TP-38 (δ configuration)
04:00	Completed TP-39 (δ minus panel 8)
	Switched to ε configuration
	Balanced flow artificially. ΔP readings indicated that panel 3 flow was high. IR panels putting 130 BTU/hr-ft^2 on all panels.
05:10	Flowmeter 47 is out
06:15	Completed TP-45
	Isolated panels 4,7, and 8 and rebalanced flows
07:45	Completed TP-46 (ε minus 4,7, and 8)
	Proceed to TP-50 (ε minus 4,7,8, panels)
	LN_2 on panels 2,3,5,6
	Panel 1 hot

15 March 1973 (Continued)

13:55	Stabilization reached for TP-50, but no panels were frozen. The 7k load plus one panel environment load being dumped by 4 panels in cold environment requires 180 lb/hr main flow.
	Form new test point to enable freezing of panels for recovery to high load conditions. New inlet temp set at 43-45°F.
15:00	Flow set to 20 lb/hr to main with occasional off and on sequences of 1 minute for freezing conditions to occur.
15:40	The 4 cold panels (2,3,5,6) show consistant edge effect with outer tube approx. 10° warmer than 3rd and 5th tubes in from edge. Probably due to inadequate insulation. Blankets conducting too much heat to panels. This is consistant with earlier problem on panel 8.
16:00	Setup to re-establish flow - increase gain 10 times on ΔP transducers to obtain positive flow indication at startup.
16:07	Positive flow indication on all 4 cold panels - return ΔP transducers to proper gain
17:05	Completed TP50A
17:10	Startup 50°/hr transient ramp - 7 to 8 tubes frozen on each cold panel.
17:24	ATM valve in system
	Panel 3 thawed approx. 30 min. after start of transient
	Panel 2 & 6 thawed approx. 40 to 45 min. after start of transient
	Panel 5 thawed approx. 55 min. after start of transient
18:10	One hour of ramp completed; all panels thawed.
	Step inlet temp to 162.4°F
19:00	Completed TP-50 (ε minus 4,7,8)
	Proceed to TP-43
23:35	Completed TP-43 (γ configuration)
	Proceed to TP-36 LN_2 on all flowing panels

16 March 1973 (day 75)

06:00	Completed TP-36 (γ minus 1,3)
06:15	Start up ramp j six tubes frozen at outlet manifold
07:18	Start increase in inlet temperature to 162.4°F
07:36	Flowmeter 56 is out
[illegible]:55	C[illegible] (γ [illegible]inus 1,3)

23 March 1973

MRS SHUTTLE TEST OPERATIONS REPORT #3

The third of three planned weeks of test operations was successfully completed on March 23, 1973. The two sided operation in Gamma configuration originally planned for the second week was performed this week due to the previous IR simulator problems which occurred in the first week's testing. New test points were added during the week to insure a full week of testing. These points were in addition to the ATM valve controlling to set point changes which were added to the test timeline just prior to the test. General test operations are summarized below.

19 March 1973 (Day 78)

00:00	Test team on station
01:45	Start pump down
04:23	Flow on-start establishing inlet temp
07:36	1.0×10^{-5} torr
10:00	Completed TP21; inlet temp 1-2°F high
10:30	Start IR cycle - Environments stable
11:15	Restart Environment
13:40	Completed TP22; High point -12:35 Low point - 13:30
15:46	Corrected flux simulators
15:50	Chamber pressure 1.5×10^{-6} Lunar Deck = 230°K
17:20	Completed TP23; Low main outlet at 14:50, High main outlet at 15:40
20:25	Completed TP24; Low at 19:20, High at 20:10
20:42	Lunar Deck = 220°K. Could possibly account for slight (2-4°F) increase in main outlet. This adds about 3 to 6 BTU/hr-ft^2 to the panel from reflection offshields.
23:30	Completed TP25; had some bad flux on Panel 2 for last half cycle. High at 21:45; Low at 22:35

20 March 1973

01:30	Completed TP26
02:50	Completed TP27
03:30	ATM valve used to control to 40°F for TP28
05:25	Completed TP28
06:00	ATM valve can't control to 40°F; switch to manual bypass required to get to 40°F
06:45	IRS stable; start 30 min hold
07:15	Start IRS transient
07:32	Freon to LN_2 HX froze on zone 1 IR simulator
08:55	Valve to HX is still frozen; zone 1 avg. temperature -29°F should be -60°F
09:20	IR zone 1 has full control
11:00	IR zones 1 and 5 are out
11:10	Completed TP29; high 9:35, low 10:20
Approx. 16:00	Total flow was reduced to 2000 lb/hr from 2200 lb/hr to stay within red line limit of pressure gauge on flow bench.
18:45	Since approx. 16:00 we have been trouble shooting inconsistent AI and AJ thermocouple temperatu data.
22:16	All in chamber redundant temperature measurements will be put on MS data channels 3 through 36.

21 March 1973

01:10	Inlet temperatures stable for TP57
04:20	Completed TP57 ATM valve set to control to 50°F
04:36	Set ATM valve to 40°F then back to 50°F to see if valve will reduce the flow from 130 to 10 lb/hr (main). Cannot control to 10 lb/hr because of leakage characteristic of valve.
07:35	Completed TP 58
08:08-08:14	ACE is down
11:40	Completed TP60
12:00	Start Transient
13:36	Popped circuit breaker on prime heater-reset

21 March 1973 (Continued)

13:38 Prime outlet dropped in response to reduced power; valve cut main flow from 900 to 700 lb/hr to compensate

13:55 Lost prime circuit breaker again

13:57 Prime outlet dropping due to reduction of power

14:00 - 14:47 Kept blowing circuit breaker; installing 60 amp breaker

16:46 Inlet temperatures stable at 162°F on both prime and main; end of ramp

17:35 Completed TP51; (we are operating with ATM valve)

18:06 Lower inlet temperature to 116°F

19:20 Completed TP52; lower inlet temperature to 75°F

20:31 Completed TP52A; change set point to 40°F

21:05 Completed TP52B

21:08 Change set point to 50°F

22:00 Completed TP52C; change set point to 70°F

23:36 Completed TP52D; change set point to 40°F

22 March 1973

02:05 Completed TP52E

04:00 Set inlet temperature to 162°F

06:05 Change set point to 70°F

07:15 Completed TP53; change to 40°F set point

08:25 Completed TP54; change set point to 50°F

09:20 Completed TP55; change set point to 70°F

11:05 Completed TP56; change set point to 40°F

12:10 Completed TP59

13:00 - 18:00 IRS panels are low on freon cause delay until they can be refilled

18:25 IR panels have reached desired fluxes

18:55 Start cycle, completed TP63 (0° point)

19:30 Completed TP63 (90° point)

20:15 Completed TP63 (180° point)

21:00 Completed TP63 (270° point)

21:44 Completed TP63 Repeat (360° point)

23:10 Start cycle per deviation 96

22 March 1973 (Continued)

23:45 Completed TP64 (90° point)

23 March 1973

00:19 NTE reported pump on IR panel 5 has quit. Going on with cycle letting panel 5 drift.

00:30 Completed TP64 (180° point)

01:00 Completed TP64 (270° point). The environments were not what was desired but can be calculated.

01:15 Completed TP64 (360° point)

02:10 Completed second 90° point, correlated well with 64. Proceed to TP 61

03:09 Pump on IR5 went out again

04:00 Pump is back on, but IRS is having trouble with the LN_2 supply to their heat exchanger

04:15 Completed TP61A (90° point)

05:00 Completed TP61B (180° point)

05:55 Completed TP61C (270° point)

06:30 Completed TP61D (360° point) Started repress sequence.